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# **The Economic Effectiveness of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions**

**Volume III**

**PB 209 953**

**Inspection/Maintenance Procedures Development**

**August 20, 1971**

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THIRTY ROCKEFELLER PLAZA  
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AND

ENVIRONMENTAL PROTECTION AGENCY  
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# The Economic Effectiveness of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions

## Volume III Inspection/Maintenance Procedures Development

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## PREFACE

This report consists of three volumes entitled: "The Economic Effectiveness of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions". The following are the titles given for each volume:

- Executive Summary, Volume I
- Modeling of Inspection/Maintenance Systems, Volume II
- Inspection and Maintenance Procedures Development, Volume III

The first volume summarizes the general objectives, approach and results of the study. The second volume presents the analytical modeling of a mandatory inspection/maintenance system and simulation results obtained using that system model. The experimental programs conducted to develop input data for the model are described in Volume III.

The work presented herein is the product of a joint effort by TRW Systems Group and its subcontractor, Scott Research Laboratories. TRW, as the prime contractor, was responsible for overall program management, experimental design, data management and analysis, and the economic-effectiveness study. Scott conducted the emission instrument evaluation and acquired and tested all of the study vehicles. Scott also provided technical assistance in selecting emission test procedures and in evaluating the test results.



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## 1. INTRODUCTION AND SUMMARY

The experiments performed to develop, characterize, and rank vehicle inspection and maintenance procedures are described in this volume. The data from these experiments are the fundamental building blocks for the economic-effectiveness model of Volume II.

The experimental data were developed from the following sequence of investigations as indicated in the flow diagram, Figure 1-1.

- An engine parameter field survey to characterize the general maintenance state of vehicle emission control systems
- A screening experiment to select the most frequent and extensive malfunctioned engine parameters
- A definitive experiment to select and evaluate the most effective parameters to maintain in an inspection as determined by combining the data from the previous two experiments

These experiments were designed to yield a consistent set of data to support the emissions models. Inspection procedures using both direct engine parameter and emission diagnosis were developed with these data. The approach is represented mathematically by the following equation relating a change in emissions (composite or diagnostic) to the frequency, extent, and sensitivity of the parameter malfunction.

$$\Delta e_j = \int_{C_{P_1}}^P (P_1) \frac{\partial e_j}{\partial P_1} dP_1 + \int_{C_{P_2}}^P (P_2) \frac{\partial e_j}{\partial P_2} dP_2 + \dots + \int_{C_{P_n}}^P (P_n) \frac{\partial e_j}{\partial P_n} dP_n$$

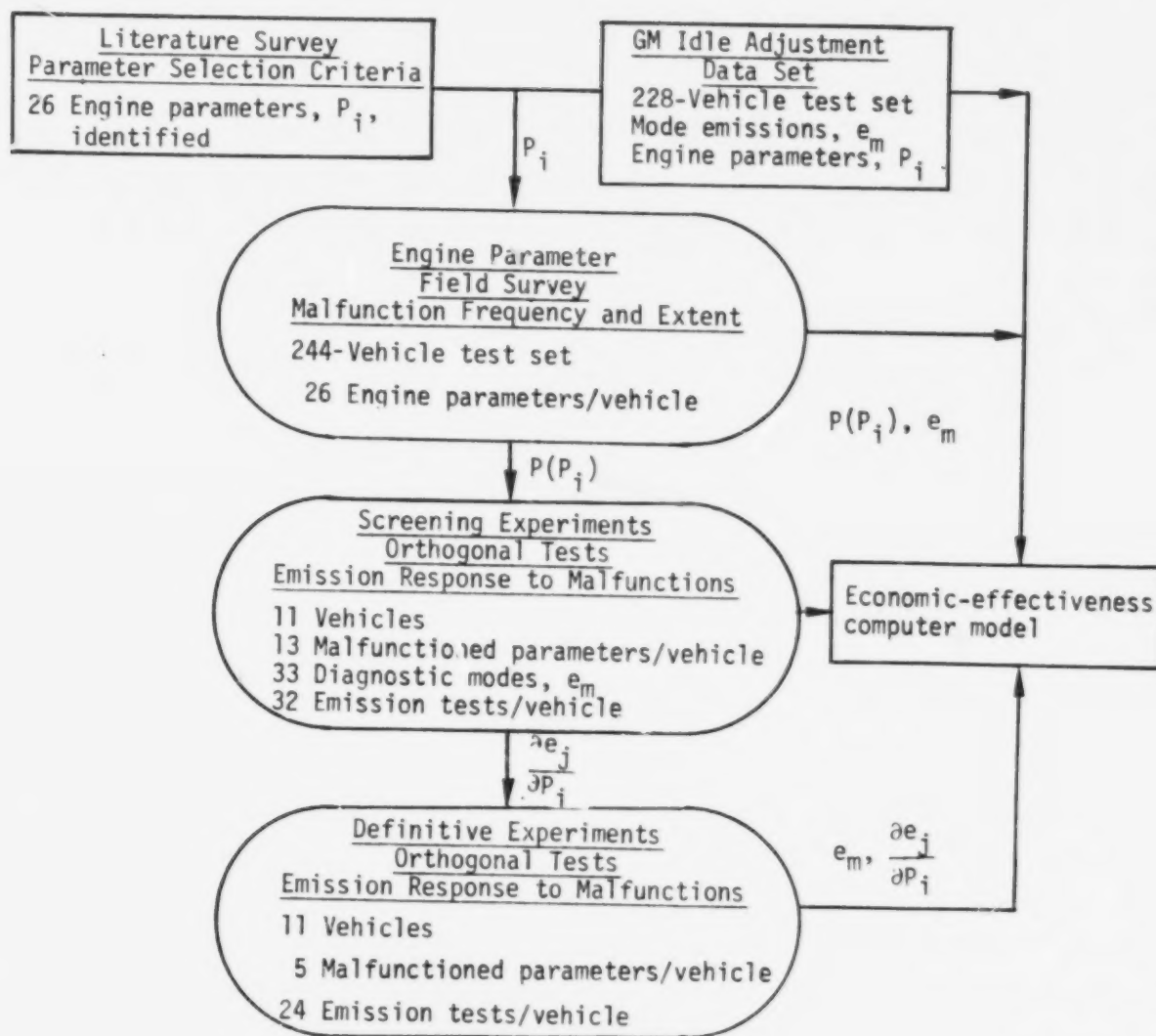


Figure 1-1. Experimental Program Flow Diagram

where:  $e_j$  =  $j^{\text{th}}$  emission, either composite or diagnostic  
 $P_i$  =  $i^{\text{th}}$  parameter  
 $CP_i$  = cut point rejection criterion on parameter distribution  
 $P(P_i)$  = distribution of parameter  $P_i$  in the general vehicle population

The distribution,  $P(P_i)$ , is developed from the parameter survey;  
the emission response,  $\partial e_j / \partial P_i$ , from the statistically designed experiments.

The following conclusions were drawn from the experimental program.

#### Parameter Survey

The most frequently occurring out-of-specification parameters which are known to have or suspected of having significant effects on emissions are:

| <u>Parameter</u>                                 | <u>Related Subsystem (See Table 2-8)</u> |
|--------------------------------------------------|------------------------------------------|
| • Ignition Timing                                | Electrical                               |
| • Vacuum advance                                 | Electrical                               |
| • Medium load induction<br>% CO at 30 and 45 mph | Performance                              |
| • Idle speed                                     | Carburetor                               |
| • Idle fuel-to-air ratio (% CO)                  | Carburetor                               |
| • Air cleaner restriction                        | Carburetor                               |
| • Float level                                    | Carburetor                               |

Based on the literature survey data, these additional parameters have significant effects on emission, although malfunction frequencies are low:

|                                 |                  |
|---------------------------------|------------------|
| • Misfire                       | Electrical       |
| • Air injection                 | Emission control |
| • Positive crankcase vent valve | Emission control |

#### Statistically Designed Experiments

The above engine parameters were studied in statistically designed experiments where in the parameters were systematically malfunctioned and exhaust emissions measured. The results are:

- o The most effective engine parameters to maintain in the general population are: secondary ignition system (spark plugs, wiring when causing misfire); idle timing, rpm and fuel-to-air ratio; air

cleaner, positive crankcase vent valve; and air injection system.

- Air cleaner restriction has a highly variable impact on CO emissions.
- Idle fuel-to-air ratio (idle CO) affects CO emissions significantly, having slight to strong nonlinear influences on emissions.
- Basic timing significantly affects NO and HC emissions under most engine loading conditions.
- Misfiring is the predominant malfunction influencing HC emissions.
- Fast idle modes are not substantially different from closed throttle in diagnosing malfunctions.
- Emissions measured under differing engine loads will diagnose the malfunctions listed above; however, no measurement uniquely points to a single malfunction.

#### Choke Experiments

- Composite emissions are not very sensitive to choke blade setting with heat riser operating nominally.
- Composite emissions are very sensitive to blade settings with the heat riser valve frozen open.

#### Air Cleaner Experiments

Eight of the eleven power trains evaluated had linear emission responses to air cleaner restrictions.

#### Experimental Technique

- The results of the air cleaner, screening, and definitive experiments were generally in good agreement with each other.
- Emission responses to engine parameters for power trains representative of the general population were generally in close agreement with each other for all parameters except cleaner restriction and vacuum advance.
- Properly designed orthogonal experiments will provide accurate and precise data on the sensitivity of emissions to engine parameters with experimental error approximately within vehicle emissions variability.



## 2. ENGINE PARAMETER SURVEY

This section describes the field survey conducted to characterize the general maintenance state of vehicle emission control systems. The survey was conducted for TRW by Scott Research Laboratories in the following sequence:

- A literature search was performed to identify those engine parameters which affect vehicle emissions.
- A sample of 244 vehicles was acquired and inspected for these engine parameters from which 227 valid tests were obtained.
- The results were summarized in a statistical format compatible with the economic-effectiveness model.

The survey results are discussed first.

### 2.1 PARAMETER SURVEY SUMMARY RESULTS

The basic data obtained during the parameter survey have not been included; however, the main conclusions of this program are summarized in Tables 2-1, 2-2, and 2-3. The raw data are available but not reported since the primary use is in determining frequency of malfunction, the mean and standard deviation of the parameters.

The most frequent out-of-specification parameters from the parameter survey, shown in Table 2-1, were ignition timing (basic and vacuum advance) point dwell, medium load induction system (as reflected by CO), idle speed, idle CO, air cleaner restriction, and float level. In addition, based on literature survey information, misfire, air injection system and positive crankcase vent valve are significant malfunctions in terms of their effect on emissions, even though nominally their failures were found in less than 12% of the population.

The ignition electrical subsystem variables (coil and required voltage) have been transformed into a single parameter, the ratio of coil available to plug required voltage, to obtain a parameter more relevant to misfire. That is, for vehicles with low ratios, misfire in the secondary might occur. The loaded mode CO and misfire essentially reflect subsystem performance. For example, misfire under load may be the result of low ratios of available-to-required voltages (values of 150% were found to result in misfire at load),



Table 2-1. Parameter Survey Summary Results

| Parameter                      | %            | %              | Cars<br>Reported | Rejection<br>Criteria        |
|--------------------------------|--------------|----------------|------------------|------------------------------|
|                                | Satisfactory | Unsatisfactory |                  | Deviation<br>from Spec.      |
| Basic Timing                   | 23.8         | 76.2           | 227              | $\geq \pm 2$ deg             |
| Total Advance                  | 65.2         | 34.8           | 227              | $\geq \pm 2$ deg             |
| Mech. Advance                  | 70.5         | 29.5           | 227              | $\geq \pm 2$ deg             |
| Vacuum Advance                 | 67.0         | 33.0           | 227              |                              |
| Plug Required Volt.            | 93.8         | 6.2            | 226              | $> 2$ kv                     |
| Coil Avail. Volt.              | 86.7         | 13.3           | 226              | $\leq 2$ kv                  |
| Point Dwell                    | 58.6         | 41.4           | 227              | $\geq 1$ deg                 |
| <u>30 mph Cruise, % CO</u>     | 82.0         | 18.0           | 127              | $> 2.5\%$ CO                 |
| Plug Required Volt.            | 92.1         | 7.9            | 227              | $> 2$ kv                     |
| Misfire Rate                   | 97.3         | 2.7            | 225              | $> 0\%$                      |
| <u>45 mph Cruise, % CO</u>     | 81.0         | 19.0           | 127              | $> 2.0\%$ CO                 |
| Plug Required Volt.            | 88.9         | 11.1           | 226              | $> 2$ kv                     |
| Misfire Rate                   | 95.6         | 4.4            | 225              | $> 0\%$                      |
| <u>60 mph Cruise, WOT</u>      |              |                |                  |                              |
| Plug Required Volt.            | 86.3         | 13.7           | 227              | $> 2$ kv                     |
| Misfire Rate                   | 90.3         | 9.7            | 227              | $> 0\%$                      |
| Idle Speed                     | 29.5         | 70.5           | 227              | $\geq \pm 30$ rpm            |
| Idle CO                        | 44.1         | 55.9           | 227              | $> 3.5\%$                    |
| Manifold Vac., in. Hg          | 80.9         | 19.1           | 225              | $\leq 2$ in. Hg              |
| Air Cleaner Restriction        | 77.1         | 22.9           | 227              | In red zone<br>of AC         |
| Float Level                    | 65.6         | 34.4           | 221              | $\geq \pm 0.06$ in.          |
| Heatriser Valve                | 78.2         | 21.8           | 225              | Frozen                       |
| PCV Performance                | 88.1         | 11.9           | 227              | $< 0$ in H <sub>2</sub> O    |
| Air Pump Performance           | 90.4         | 10.6           | 50               | $\leq 0.2\%$ CO <sup>+</sup> |
| Vacuum Leaks                   | 97.7         | 2.3            | 224              | Disconnected                 |
| +CO disconnected -CO connected |              |                |                  |                              |

Table 2-2. Statistical Summary  
All Years, Engine Modification Systems

| Variable Number | Parameter (units)                              | Estimate of Mean $\bar{X}$ | Estimate of Standard Deviation S | Sample Size |
|-----------------|------------------------------------------------|----------------------------|----------------------------------|-------------|
| 1               | $\Delta$ Timing, deg                           | 0.7                        | 5.8                              | 135         |
| 2               | Vacuum Advance, deg                            | 19.8                       | 6.7                              | 136         |
| 3               | % Available Voltage (Coil Avail/Plug Req'd), % | 308                        | 155                              | 133         |
| 4               | Misfire Rate* at 30 mph, %                     | 12                         | 0                                | 6           |
|                 | at 45 mph, %                                   | 15.3                       | 5.4                              | 11          |
|                 | at 60 mph, %                                   | 17.6                       | 8.4                              | 22          |
| 5               | ICO %                                          | 3.69                       | 1.94                             | 136         |
| 6               | $\Delta$ IRPM, rpm                             | 6                          | 95                               | 136         |
| 7               | A/C Restriction, deg                           | 27                         | 45                               | 136         |
| 8               | PCV Pressure, in. H <sub>2</sub> O             | -0.4                       | 0.6                              | 136         |
| 9               | Air Pump Pressure, psi                         | N. A.                      | N. A.                            | N. A.       |
| 10              | Odometer Reading, mi                           | 28671                      | 18514                            | 136         |

\*Based on those vehicles from total population actually misfiring.

Table 2-3. Statistical Summary  
All Years, Air Injection Systems

| Variable Number | Parameter (units)                              | Estimate of Mean $\bar{X}$ | Estimate of Standard Deviation S | Sample Size |
|-----------------|------------------------------------------------|----------------------------|----------------------------------|-------------|
| 1               | $\Delta$ Timing, deg                           | 1.3                        | 5.7                              | 91          |
| 2               | Vacuum Advance, deg                            | 18.4                       | 5.5                              | 91          |
| 3               | % Available Voltage (Coil Avail/Plug Req'd), % | 295                        | 91                               | 91          |
| 4               | Misfire Rate* at 30 mph, %                     | 12                         | 0                                | 6           |
|                 | at 45 mph, %                                   | 15.3                       | 5.4                              | 11          |
|                 | at 60 mph, %                                   | 17.6                       | 8.4                              | 22          |
| 5               | ICO %                                          | 3.77                       | 1.85                             | 91          |
| 6               | $\Delta$ IRPM, rpm                             | -32                        | 88                               | 91          |
| 7               | A/C Restriction, deg                           | 59                         | 54                               | 91          |
| 8               | PCV Pressure, in. H <sub>2</sub> O             | -0.2                       | 0.2                              | 90          |
| 9               | Air Pump Pressure, psi                         | 4.1                        | 2.2                              | 90          |
| 10              | Odometer Reading, mi                           | 40656                      | 16494                            | 90          |

\*Based on those vehicles from total population actually misfiring.

severe mistiming, or short circuits in the secondary (plugs or wires) or combinations thereof.

Tables 2-2 and 2-3 summarize the mean values and standard deviations of all vehicles and give a breakdown by air injection and engine modification vehicle engine parameters. The difference between the mean value of the actual measurement and the manufacturer's specification or the nominal (0) state of the engine is an indication of the severity of the malfunction.

Parameters of most interest in an enforced inspection/maintenance program are those which are frequently out of specification and result in high emissions. High emissions will result if a parameter with small effect on emissions is grossly out of specification with regard to extent and frequency, or if a less frequent malfunction has a great effect on emissions. In the former, either one- or two-sided inspections would be effective (using rejection criteria on both sides of a specification tolerance band). In addition, a one-sided inspection of parameters with large variability on the side which reduces emissions may be economically effective. The parameters presented in Tables 2-2 and 2-3 fulfill this requirement. Those which could be effectively inspected in one- or two-sided inspection are idle CO and timing. The remaining parameters could most effectively be inspected using a one-sided test.

Of the parameters evaluated, some are constrained by physical design or definition to values greater than some constant value, usually zero. Because of this, their distribution functions are not normally distributed, particularly when the mean values are close to zero. All of the emission measurements, air cleaner restriction, air pump restriction, and positive crankcase ventilation (crankcase pressure) have skewed distributions resulting from constraints. A frequency diagram for air cleaner restriction, as shown in Figure 2-1, approaches a binomial distribution. The preponderance of air cleaners (50%) are at the nominal state. An extremely long "tail" over the full range of the instrument measurement capability starts well to the left of the mean value. One can assume that a certain percent of the population has neglected air cleaner maintenance.

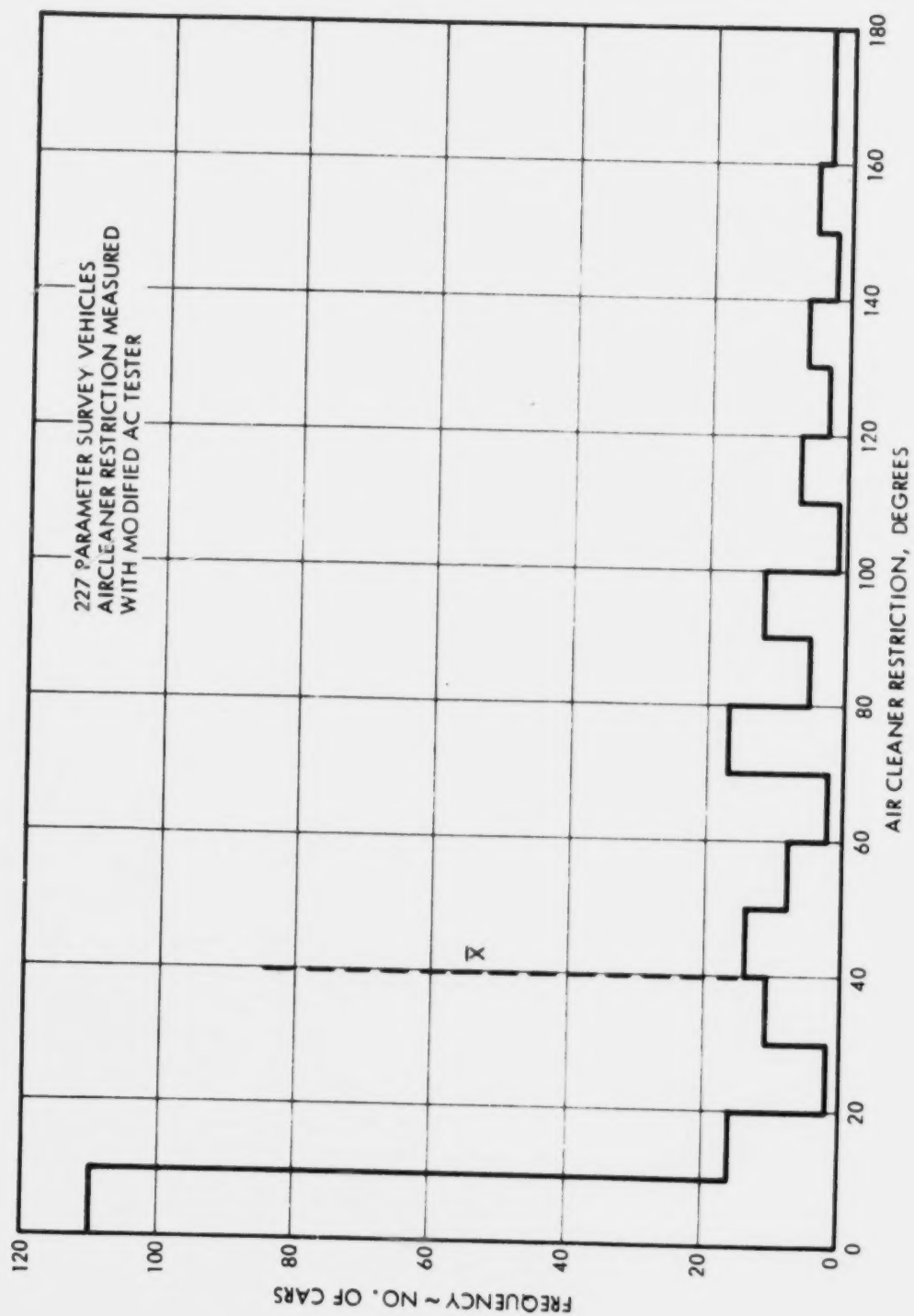


Figure 2-1. Frequency Diagram for Air Cleaner Restriction

### 2.1.1 Primary and Secondary Ignition Subsystem Evaluation

Some of the parameters measured (loaded CO and misfire, for example) reflect the overall condition of a subsystem rather than a specific component. A more detailed breakdown of the component performance for those vehicles having misfire appears in Table 2-4. The misfire at load is compared against the ratio of available-to-required voltage, deviation from manufacturer's specification of coil available voltage and the dynamic compression test. The following conclusions were drawn:

- The cylinder balance (dynamic compression) test reflected that 2.2% of the total population of vehicles were misfiring at 1500 rpm, no load (5 failures out of 226 vehicle samples).
- A shorted secondary ignition component (wire or plug) was the predominant mode of failure.
- Misfire is generally poorly correlated to coil available voltage at low engine load.
- On 25% of the vehicles misfiring at wide open throttle, low ratios of available-to-required voltage were also evident.

In summary, there appears to be poor correlation between the electrical subsystem variables measured and misfire. Approximately 50% of the vehicles misfiring under loads equivalent to the Federal cycle were also misfiring under the 1500 rpm, no-load condition. This suggests that an idle HC diagnostic inspection might be an effective procedure for identifying this malfunction.

### 2.1.2 Induction Subsystem Analysis

A similar analysis was performed for the induction system components known to affect loaded mode CO. What was sought was an estimation of the number of induction system failures likely to be in the main and power circuits of the carburetor rather than in related components, such as PCV, air cleaner and float level. Refer to Volume II, Table 3-2 for table of failures. Half of the failures shown in the table are related to external

Table 2-4. Typical Electrical System Malfunctions and Their Correlation to Misfire

| Parameter Survey Study |        |                      |     |                   |     |                                |                      |    |    |    |    |    |    |    |    |
|------------------------|--------|----------------------|-----|-------------------|-----|--------------------------------|----------------------|----|----|----|----|----|----|----|----|
| Car No.                | 30 mph | Misfire, %<br>45 mph | WOT | Deviation of Coil |     | Available<br>to Required Volt. | Dynamic Compression* |    |    |    |    |    |    |    |    |
|                        |        |                      |     | Available, kv     | -10 |                                | 9                    | 7  | 11 | 9  | 11 | 0  | 9  | 9  |    |
| 23                     | 12     | 12                   | 24  |                   | -10 | 2.44                           |                      | 9  | 7  | 11 | 9  | 11 | 0  | 9  | 9  |
| 65                     | 0      | 0                    | 36  |                   | 4   | 3.00                           |                      | 8  | 8  | 10 | 10 | 9  | 9  | 10 | 10 |
| 66                     | 12     | 12                   | 12  |                   | 4   | 2.57                           |                      | 8  | 7  | 3  | 7  | 9  | 9  | 0  | 7  |
| 114                    | 12     | 12                   | 12  |                   | 4   | 4.50                           |                      | 8  | 8  | 10 | 8  | 8  | 0  | 8  | 8  |
| 127                    | 0      | 0                    | 24  |                   | 0   | 2.28                           |                      | 10 | 10 | 9  | 10 | 11 | 9  | 10 | 9  |
| 160                    | 0      | 20                   | 20  |                   | 4   | 1.63                           |                      | 10 | 8  | 7  | 9  | 7  | 9  | 10 | 7  |
| 177                    | 0      | 0                    | 6   |                   | 4   | 2.25                           |                      | 10 | 9  | 10 | 9  | 11 | 10 | 11 | 9  |
| 192                    | 0      | 0                    | 12  |                   | -8  | 1.53                           | Transistor ignition  |    |    |    |    |    |    |    |    |
| 211                    | 12     | 24                   | 24  |                   | -4  | 2.00                           |                      | 5  | 5  | 1  | 6  | 5  | 5  | 5  | 3  |
| 212                    | 0      | 12                   | 12  |                   | -3  | 4.18                           |                      | 9  | 5  | 6  | 10 | 5  | 7  | 8  | 8  |
| 229                    | 12     | 12                   | 12  |                   | 0   | 3.54                           |                      | 8  | 7  | 7  | 8  | 0  | 9  | 6  | 8  |
| 243                    | 12     | 25                   | 25  |                   | 0   | 2.93                           |                      | 6  | 7  | 8  | 5  | 5  | 6  | 6  | 7  |
| 247                    | 0      | 0                    | 12  |                   | 0   | 2.60                           |                      | 7  | 8  | 7  | 6  | 8  | 6  | 8  | 7  |

\* rpm drop when cylinder spark plug shorted



component failure rather than metering malfunctions. This analysis indicated that between 9 and 10% of the parameter survey vehicles had these carburetion malfunctions, assuming the rejection points of 2.5 and 2.0% CO at 30 and 45 mph road loads, respectively. The unknown is how many of these vehicles had rich fuel adjustments when new or rebuilt. It is difficult (with the exception of the accelerator pump/power jet actuator) to hypothesize failure mechanisms for carburetor main meter circuits which would increase fuel flow. Data similar to that of Volume II, Table 3-2 indicate that only 50% of the vehicles were common to both sets of data (vehicle sets obtained by rejecting the 30 and 45 mph loaded CO mode emissions data). It is a demonstrated fact that idle CO adjustments of sufficient severity will affect CO emission in the lower loaded modes, depending on specific power train configuration. The data indicated that 88% of the vehicles which failed the 30 mph CO criteria had idle CO emissions as high or in excess of 5%. These rich adjustments, on an average, would be anticipated to increase CO at 30 mph from 0.5 to 1.0%. Carry-over of rich, idle CO in the heavier loaded 45 mph mode is substantially less than in the 30 mph mode.

#### 2.1.3 Air Pump Malfunction Evaluation

Two diagnostic approaches to characterizing air pump malfunctions were evaluated:

- Application of the manufacturers' field test specifications
- Inference from CO emission measurements under load

In the former, a pressure measurement at the air pump discharge (either dead headed or free flowing) is made. Low pressures indicate a leaking pump or bypass valve. The emission measurement technique requires CO to be measured under load with the pump operating and disconnected. This is a more reliable indication of malfunction, little or no changes being indicative of inoperability. The loaded mode was selected to minimize the influence of the idle adjustment on air injection effectiveness. These adjustments, particularly idle CO (Section 4), have a significant effect on pump performance and confuse a diagnosis in the idle mode. Comparisons of vehicles

rejected by both criteria indicate extremely poor correlation between procedures. Of the six known air injection system failures, only two were identified with the pump discharge measurement. It is not known why the pump pressure diagnosis was so poorly correlated. However, the procedure only diagnoses those components upstream of the pump discharge. Restrictions or leaks in the manifolding and injection nozzles are not diagnosed.

#### 2.1.4 Comparison with GM Data

The APRAC CAPE-13 Committee supplied the GM idle adjustment program basic data set. This data set on 228 emission-controlled California vehicles consisted of as-received and post-idle adjustment mode and composite emissions, scope diagnosis, and idle rpm and timing measurements. These data were compared with idle adjustments from the engine parameter survey for air injection and engine modification vehicles, respectively (see Table 2-5). The mean biases from specification or nominal state and their standard deviations agree fairly well between data sets. The most significant deviations are between engine modification vehicles for idle rpm.

Estimates of failure rates for the air injection system and misfire at idle were made. Air pump malfunctions for the GM set were estimated from mode dilution correction values. The hypothesis applied to fail this subsystem is that the dilution factor should exceed unity for a nominal system since excess pump air dilutes the exhaust gas. Application to the idle mode must be done with some care as idle adjustments can produce dilution corrections of 1.1 or less, even when the air injection system is functioning properly. This is most dramatically shown by using the failure criterion, dilution correction equal to or less than 1.1 on the as received vehicles (see Table 2-6).

Table 2-5. Comparison of Parameter Survey with General Motors Idle Adjustment Data

| Parameter                                                                                                                                                                                        | GM Data           |                   |             | TRW Parameter Survey Data |                |             |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------|-------------|---------------------------|----------------|-------------|
|                                                                                                                                                                                                  | Mean              | Standard Error    | Sample Size | Mean                      | Standard Error | Sample Size |
| Timing, Degrees                                                                                                                                                                                  |                   |                   |             |                           |                |             |
| Air Injection                                                                                                                                                                                    | 0.55              | 3.45              | 124         | 1.3                       | 5.7            | 91          |
| Engine Modification                                                                                                                                                                              | 0.89              | 4.54              | 105         | 0.7                       | 5.8            | 135         |
| RPM                                                                                                                                                                                              |                   |                   |             |                           |                |             |
| Air Injection                                                                                                                                                                                    | -54               | 85                | 124         | -32                       | 88             | 91          |
| Engine Modification                                                                                                                                                                              | -28               | 77                | 105         | 6                         | 95             | 135         |
| Idle CO, %                                                                                                                                                                                       |                   |                   |             |                           |                |             |
| Air Injection (pump disconnected)                                                                                                                                                                | 3.42 <sup>†</sup> | 2.21 <sup>†</sup> | 124         | 3.77                      | 1.85           | 91          |
| Engine Modification                                                                                                                                                                              | 4.3               | 3.27              | 105         | 3.69                      | 1.94           | 135         |
| Air Pump, %                                                                                                                                                                                      | 5.8*              |                   |             | 10**                      |                |             |
| Not Operating                                                                                                                                                                                    |                   |                   |             |                           |                |             |
| Misfire, % at Idle                                                                                                                                                                               | 2.2               |                   |             | 2.2                       |                |             |
| <p>* Inferred from dilution correction at 30 mph mode.</p> <p>** Inferred from no change in CO when pump hose disconnected, 50-vehicle sample.</p> <p>† Corrected for disconnected air pump.</p> |                   |                   |             |                           |                |             |

Table 2-6. Air Injection System Diagnosis Using Several Inspection Policies Based on Dilution Correction

| Inspection Policy,<br>Dilution Correction†                                                                                                                                                                                           | GM Idle Adjustment Program  |                      |  | Actual No.*<br>Failures | Errors of**<br>Commission |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|----------------------|--|-------------------------|---------------------------|
|                                                                                                                                                                                                                                      | Maintenance<br>State        | Vehicles<br>Rejected |  |                         |                           |
| 1.1 at idle                                                                                                                                                                                                                          | As received                 | 27                   |  | 7                       | 20                        |
| 1.0 at idle                                                                                                                                                                                                                          | As received                 | 7                    |  | 6                       | 1                         |
| 1.1 at idle                                                                                                                                                                                                                          | Idle parameters<br>adjusted | 7                    |  | 7                       | 0                         |
| 1.2 at 30 mph                                                                                                                                                                                                                        | As received                 | 5                    |  | 5                       | 0                         |
| <p>* Total number of vehicles in set with air injection system malfunctions was seven.</p> <p>** Vehicles which were rejected but not actually failed.</p> <p>† Dilution correction = <math>\frac{15}{6HC + 0.5CO + CO_2}</math></p> |                             |                      |  |                         |                           |

## 2.2 PARAMETER SELECTION CRITERIA

The primary task in developing reliable inspection and maintenance procedures is to select engine parameters most likely to have adverse effects on emissions. Selection of the parameters used in the development program was based on results of a comprehensive survey of the literature (References 1 - 10). Forty-four components and conditions (see Table 2-7) were found to have potential effects on exhaust emissions. Besides effects on exhaust emissions, parameter selection criteria included consideration of inspection and maintenance costs and their ability to malfunction or slip out of adjustment. Final selection was made of 26 inspection parameters capable of being diagnosed with a high probability. These items appear on the engine parameter inspection sheet (see Table 2-8) used in this program.

An inspection procedure was developed and implemented to identify the source area of indicated failure and, wherever possible, the specific component or part causing the trouble. This procedure purposely required the use of conventional diagnostic equipment, except for a chassis dynamometer.

Some malfunctions could occur without detection under the inspection procedure used. These include primary ignition circuit condenser; distributor point cam and drive; carburetor choke system and pump circuit; air cleaner hot air door thermostat; air injection pump gulp or dump valve, check valves and hoses; combustion chamber deposits; cooling system temperature; and exhaust system back pressure. Also, the procedure could detect fuel system malfunctions but fail to clearly identify their specific sources, such as carburetor deposits, bowl vent, hot idle compensator and fuel supply. For these reasons, the criteria for engine parameter selection stressed high probability of detection and identification of malfunctions or maladjustments.

Table 2-7. Engine Parameters Which Affect Exhaust Emissions

1.0 Ignition System

1.1 Electrical, Secondary

- Spark plugs
- Wires
- Distributor cap
- Rotor
- Coil (secondary)

1.2 Electrical, Primary

- Points
- Condenser
- Coil (primary)
- Primary resistance (ballast)
- Alternator circuit

1.3 Distributor, Mechanical

- Timing
- Point dwell
- Vacuum advance
- Mechanical advance
- Cam
- Distributor drive (excessive end play)

2.0 Carburetor

- 2.1 Idle Circuit (speed & mixture)
- 2.2 Low Speed (off idle)
- 2.3 Choke (including fast idle)
- 2.4 Float Circuit
- 2.5 High Speed (part load)
- 2.6 High Speed (full load)
- 2.7 Deposits
- 2.8 Pump Circuit
- 2.9 Air Cleaner Element
- 2.10 Air Cleaner Thermostat
- 2.11 Fuel Supply (filter & pressure)
- 2.12 Bowl Vents
- 2.13 Hot Idle Compensator



Table 2-7. Engine Parameters Which Affect Exhaust Emissions (Cont.)

3.0 Exhaust Emission Devices

3.1 Air Injection Reactor Systems:

- Pump (including relief valve)
- Gulp valve (or bypass)
- Check valves
- Hoses

3.2 Engine Modifications

- Vacuum advance control valve
- Vacuum retard (idle only)
- Mechanical retard (idle only)
- Fuel shutoff (decel. only)

4.0 Engine

- 4.1 Combustion Chamber Deposits
- 4.2 Valve Condition (compression)
- 4.3 Intake Manifold Vacuum (leaks)
- 4.4 Blowby (PCV systems & rings)
- 4.5 Heat Riser Control
- 4.6 Cooling System (temperature)
- 4.7 Exhaust Back Pressure (muffler)

Table 2-8. Engine Parameter Inspection

Car No. 114Performed by  
Scott Research Laboratories, Inc.

|                                      |                                              |                           |              |                        |
|--------------------------------------|----------------------------------------------|---------------------------|--------------|------------------------|
| <b>1. Vehicle Identification No.</b> |                                              |                           |              |                        |
| 1.1 Year, Make                       | 68 Dodge                                     | 1.7 Engine Size, CID      | 383          |                        |
| 1.2 Model                            | Monaco 500                                   | 1.8 Carb, Make (#bbls)    | Carter 4V    |                        |
| 1.3 License No.                      | 6H3429 New York                              | 1.9 Transmission          | Auto         |                        |
| 1.4 Odo., Miles                      | 22803                                        | 1.10 Exh. Emission System | Eng. Mod     |                        |
| 1.5 Name                             | N.E. Knox                                    | 1.11 Crankcase Ems System | Closed       |                        |
| 1.6 Address                          | 593 Courtland Dr. San Bernardino, California |                           |              |                        |
| <b>2. Electrical Inspection</b>      |                                              |                           |              |                        |
|                                      | Measured                                     | Spec.                     | Departure    | Satisfactory<br>Yes No |
| 2.1 Basic Timing, deg                | +11                                          | +5                        |              | X                      |
| 2.2 Total Advance, deg               | 45                                           | 41-50                     |              | X                      |
| 2.3 Mech. Advance, deg               | 26                                           | 23-26                     |              | X                      |
| 2.4 Vacuum Advance, deg              | 19                                           | 18-24                     |              | X                      |
| 2.5 Plug Req'd Volt, kv              | 16                                           | 20                        |              | X                      |
| 2.6 Coil Avail. Volt, kv             | 36                                           | 28-32                     |              | X                      |
| 2.7 Point Dwell, deg                 | 29                                           | 28-33                     |              | X                      |
| 2.8 Dynamic Compression, %           | 1. <u>8</u>                                  | 2. <u>8</u>               | 3. <u>10</u> | 4. <u>8</u>            |
| Change in Speed                      | 5. <u>8</u>                                  | 6. <u>0</u>               | 7. <u>8</u>  | 8. <u>8</u>            |
| <b>3. Performance Diagnosis</b>      |                                              |                           |              |                        |
| 3.1 30 mph Cruise at 16 in. hg       | CO, %                                        | 1.5                       |              | X                      |
| • Plug Req'd Volt, kv                | 8                                            |                           |              | X                      |
| • Misfire Rate, %                    | 12                                           |                           |              | X                      |
| 3.2 45 mph, at 8 in. hg              | CO, %                                        | 1.8                       |              | X                      |
| • Plug Req'd Volt, kv                | 9                                            |                           |              | X                      |
| • Misfire Rate, %                    | 12                                           |                           |              | X                      |
| 3.3 60 mph, WOT                      |                                              |                           |              |                        |
| • Plug Req'd Volt, kv                | 12                                           |                           |              | X                      |
| • Misfire Rate, %                    | 12                                           |                           |              | X                      |

Table 2-8. Engine Parameter Inspection (Cont.)

| Car No. <u>114</u>                                        |                 |              |                     |            |           |
|-----------------------------------------------------------|-----------------|--------------|---------------------|------------|-----------|
| 4. <u>Carburetor Inspection</u>                           |                 |              | <u>Satisfactory</u> |            |           |
|                                                           | <u>Measured</u> | <u>Spec.</u> | <u>Departure</u>    | <u>Yes</u> | <u>No</u> |
| 4.1 Idle Speed, rpm (N or D)                              | 560N            | 650N         |                     |            | X         |
| 4.2 Idle CO, % <sup>*</sup>                               | 5.0             |              |                     |            | X         |
| 4.3 Manifold Vacuum, in. hg                               | 17              |              |                     | X          |           |
| 4.4 Air Cleaner, angle deg                                | 5               |              |                     | X          |           |
| 4.5 Float Level, in.                                      | 7/32            | 7/32         |                     | X          |           |
| 4.6 Heat Riser Valve<br>(None, Free, Froze)               | Free            |              |                     | X          |           |
| 5. <u>Emission Control</u>                                |                 |              |                     |            |           |
| 5.1 PCV Perf. at Idle, in. H <sub>2</sub> O <sup>**</sup> | -0.2            |              |                     | X          |           |
| 5.2 Air Pump Performance, psi                             | None            |              |                     |            |           |
| 5.3 Vac Leaks (Yes or No)                                 | No              |              |                     | X          |           |
| 5.4 Idle Speed (rpm in N or D)                            | 560-N           | 650-N        |                     |            | X         |
| Remarks: _____                                            |                 |              |                     |            |           |
| _____                                                     |                 |              |                     |            |           |
| _____                                                     |                 |              |                     |            |           |

\* Without Air on Cars with Air Pumps.

\*\* Vacuum is minus (-), and Pressure is plus (+).

### 2.3 VEHICLE SAMPLE IDENTIFICATION AND ACQUISITION

Various sample sources from which to select vehicles for characterizing their general maintenance states were considered. Requirements for the source selection were:

- A large population of 1966-69 California vehicles
- Minimum acquisition costs
- Typical maintenance states

Vehicle sources considered were: 1) random selections from within the San Bernardino area; 2) constrained selections from large industrial parking lots; and 3) constrained selections from commercial sources such as rental agencies or used car lots. The second approach was selected.

Although a completely random fleet of vehicles would statistically be preferable, the cost and logistics of acquiring these vehicles was judged to be excessive. For example, an identification, pickup, delivery, and possibly an incentive system would be required since vehicles would be held as long as 4 hours. Incentive has the potential danger of biasing the sample toward the more poorly maintained vehicles. The attendant scheduling problems would also increase the cost of the experiment. Therefore, this approach was rejected. The use of commercial vehicles (i.e., rental vehicles or used car lots) was rejected on the basis of both cost and poor matching of maintenance states within the general population. The identification and scheduling of these vehicles is significantly less costly than a random selection.

The best compromise was to borrow vehicles from industrial parking lots during working hours. Enough vehicles were picked up in the morning to establish a test reserve to assure maximum use of manpower and facilities. To the extent that the industrial employees represent a micro-scale of the general population, their vehicles are a valid statistical sample.

To support this decision a questionnaire was circulated to TRW Systems and Aerospace Corporation employees to determine their auto maintenance habits, vehicle attributes, and willingness to loan their vehicles at no cost to the program (see Figure 2-2). These results indicated sufficient vehicles were available to form a test fleet of 250 cars reflecting national population characteristics in terms of make, model and year. The average indicated tune-up maintenance interval for the fleet was slightly in excess of 12 months.

Vehicles were acquired from two large industrial sites — TRW Systems and Aerospace Corporation parking lots — in the vicinity of the Scott Research Laboratory (SRL) San Bernardino test facility using the following procedure:

- Vehicles were selected randomly from the inventory of available vehicles as reflected by the questionnaire.
- A reserved area within the parking lot was allocated for those vehicles to be tested within a given day.
- The vehicle owner was notified three days before by mail and with a follow-up call the day before his vehicle was tested to deliver his vehicle to the designated area.
- SRL drivers retrieved and returned vehicles from the reserved parking lot.

Two hundred and forty-four vehicles were acquired from which 227 valid tests were obtained. The distribution of the acquired vehicles relative to the US population is shown in Figure 2-3 and a detailed matrix in Table 2-9. The population matching is good across model and model years with the exception of American Motors Corp. (AMC) vehicles. Since AMC vehicles are a small percent of the sample, this deviation will not significantly affect the statistical results. The 1966-67 and 1968-69 vehicle groups are well matched to the population (i.e., 50% in each group).

Name  LAST NAME, LEAVE ONE SPACE, THEN FIRST INITIAL

Employee number

Do not write in boxes containing decimal points

Automobile make  year ('66 or later, please)   
model

Engine displacement (if known): cubic inches  horsepower   
number of cylinders: (check one) eight  six  four

Transmission: automatic  manual  Air conditioning: yes  no

When purchased: year  month  what state

How many years longer do you expect to keep this automobile?

Present speedometer mileage

Average mileage driven per year

Number of miles per day spent commuting

Average number of miles per day car is driven on the freeway

Principal driver: male  female  married  single   
age: 16 - 25  26 - 40  41 - 65  over 65

What brand name of gasoline do you normally purchase?   
regular  premium

Who normally tunes up your car (spark plugs, distributor, carburetor)?  
auto dealer  service station  diagnostic station  yourself

How often? less than 6000 miles  6000 - 12000 miles  more than 12000 miles

Are you willing to participate in this type of program with the car described above? yes  no

After you have finished, please fold the questionnaire so that the return address shows and deposit it in the company mail.

Figure 2-2. Sample Questionnaire



**Test Vehicle Population - 244**

**Distribution, Percent**                      0      10      20      30      40      50

**American Motors**

U. S. Population



Test Sample



**Chrysler**

U. S. Population



Test Sample



**Ford**

U. S. Population



Test Sample



**General Motors**

U. S. Population



Test Sample



**Foreign**

U. S. Population



Test Sample



**Figure 2-3. Test Vehicle Population Compared with U. S. Vehicle Population**

Table 2-9. Engine Parameter Maladjustment Survey Test  
Vehicle Population

| Make                               | Number of Vehicles |                |                |                |               | Total            | Population Distribution% |                    |
|------------------------------------|--------------------|----------------|----------------|----------------|---------------|------------------|--------------------------|--------------------|
|                                    | 66                 | 67             | 68             | 69             | 70            |                  | Sample                   | U. S.              |
| <u>American Motors Corporation</u> |                    |                |                |                |               |                  |                          |                    |
| Rambler                            | 1                  | 1              | 1              | 0              | 0             | $\frac{3}{3}$    | $\frac{1.2}{1.2}$        | $\frac{3.6}{3.6}$  |
| <u>Chrysler Corporation</u>        |                    |                |                |                |               |                  |                          |                    |
| Chrysler                           | 1                  | 1              | 1              | 5              | 0             | 8                | 3.3                      | 2.4                |
| Dodge                              | 8                  | 4              | 6              | 7              | 0             | 25               | 10.2                     | 6.5                |
| Plymouth                           | $\frac{6}{15}$     | $\frac{1}{6}$  | $\frac{4}{11}$ | $\frac{1}{13}$ | $\frac{0}{0}$ | $\frac{12}{45}$  | $\frac{4.9}{18.4}$       | $\frac{7.7}{16.6}$ |
| <u>Ford Motor Company</u>          |                    |                |                |                |               |                  |                          |                    |
| Ford                               | 21                 | 10             | 9              | 15             | 3             | 58               | 23.8                     | 19.7               |
| Lincoln                            | 1                  | 1              | 0              | 0              | 0             | 2                | 0.8                      | 0.0                |
| Mercury                            | $\frac{6}{28}$     | $\frac{1}{12}$ | $\frac{0}{9}$  | $\frac{2}{17}$ | $\frac{0}{3}$ | $\frac{9}{69}$   | $\frac{3.7}{28.3}$       | $\frac{3.6}{23.3}$ |
| <u>General Motors Corporation</u>  |                    |                |                |                |               |                  |                          |                    |
| Buick                              | 5                  | 3              | 4              | 3              | 0             | 15               | 6.2                      | 6.5                |
| Cadillac                           | 1                  | 2              | 1              | 0              | 0             | 4                | 1.6                      | 2.0                |
| Chevrolet                          | 15                 | 9              | 13             | 11             | 0             | 48               | 19.7                     | 23.0               |
| Oldsmobile                         | 6                  | 4              | 7              | 1              | 0             | 18               | 7.4                      | 6.1                |
| Pontiac                            | $\frac{9}{36}$     | $\frac{5}{23}$ | $\frac{4}{29}$ | $\frac{4}{19}$ | $\frac{1}{1}$ | $\frac{23}{108}$ | $\frac{9.4}{44.3}$       | $\frac{9.3}{46.9}$ |
| <u>Foreign</u>                     |                    |                |                |                |               |                  |                          |                    |
| Volkswagen                         | 2                  | 0              | 4              | 3              | 0             | 9                | 3.7                      | 5.6                |
| Others                             | $\frac{1}{3}$      | $\frac{0}{0}$  | $\frac{4}{8}$  | $\frac{5}{8}$  | $\frac{0}{0}$ | $\frac{10}{19}$  | $\frac{4.1}{7.8}$        | $\frac{4.0}{9.6}$  |
| Grand Total                        | 83                 | 42             | 58             | 57             | 4             | 244              | 100.0                    | 100.0              |

## 2.4 VEHICLE INSPECTION PROCEDURE

### 2.4.1 Test Station Arrangement

The parameter inspection was conducted at two test stations. Idle % CO and float level were measured at a second test site for accessibility to exhaust analysis equipment. The inspection procedure (see Figure 2-4) provided maximum test efficiency for a two-man crew with quick access to all test equipment. Engine warmup was assured as all test vehicles were driven approximately five miles from the industrial parking lot to the Scott Research Laboratories' test facility.

### 2.4.2 Measurement Procedure and Test Equipment

The procedures and equipment used for the parameter inspection were based on accepted shop procedures. Commonly available equipment was used wherever possible as it was impractical to attempt the survey on a more sophisticated level. Specifications used were obtained primarily from manufacturers' tuneup guides and shop manuals (see Figure 2-5). Certain information was not always available, however, which made it necessary to establish some specifications or criteria for purposes of quantifying inspection results. These specifications were used when neither manufacturers' or general shop manuals provided complete information. The actual procedures used are described in Table 2-10 and refer to the individual items on the inspection sheet of Table 2-8. In addition to the procedures detailed in Table 2-10, observations were made of diagnoses based on ignition scope patterns.

Complete specifications were not available for required spark plug voltage, available coil voltage, performance diagnosis, idle % CO, air cleaner restriction, PCV system performance at idle, and air pump performance at idle. For these inspection items, specifications were derived from whatever literature was available. Specifications for spark plug required voltage and coil available voltage were derived from the ignition scope operating manual. The PCV system and air pump performance specifications were derived from Automobile Smog Control Manual, by Harold T. L. Glenn. The AC air cleaner tester indicated that a reading of 90 to 135 degrees was the upper range for an acceptable air cleaner element. The upper limit for

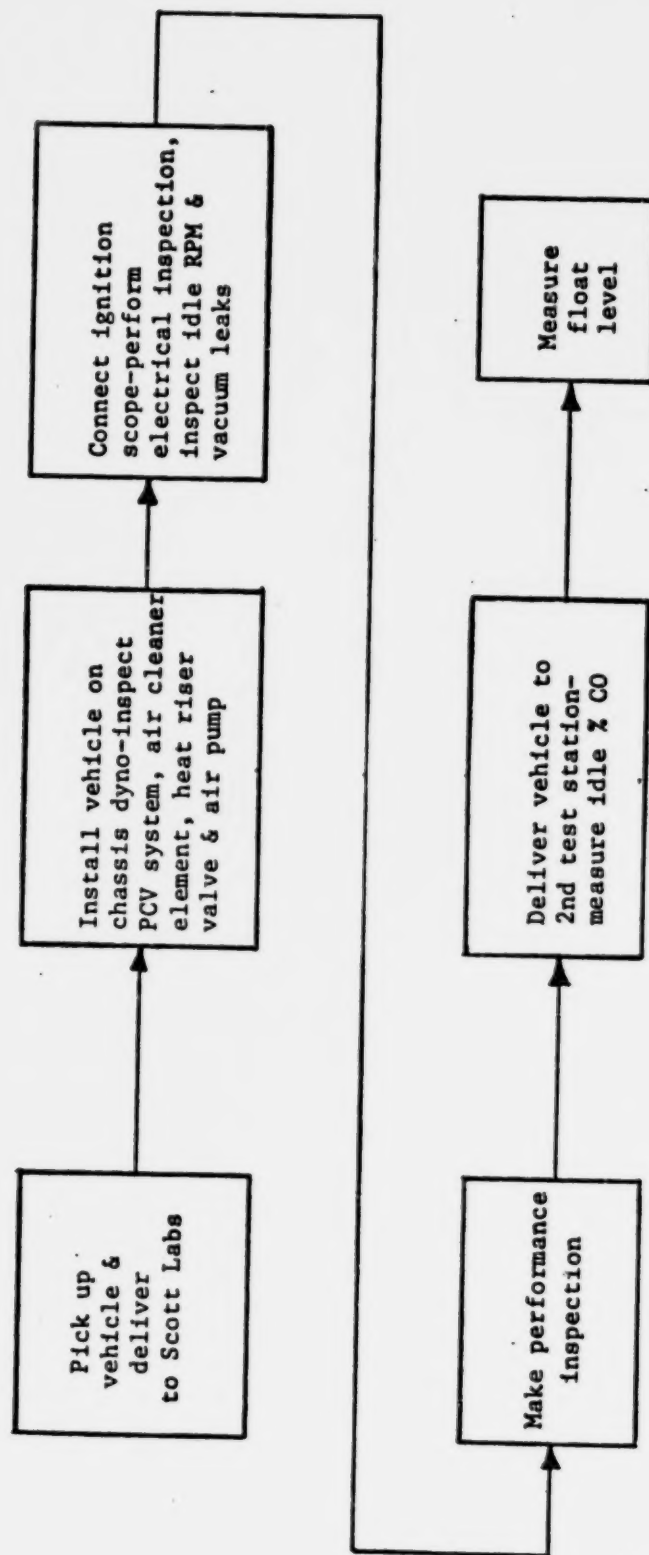


Figure 2-4. Parameter Inspection Procedure Sequence

# 917 1968 DODGE-PLYMOUTH-CHRYSLER V8 383 CU. IN. ENGINE 3 HP W/4 BBL. CARB.

ENGINE 383 Cu. In.



Firing Order 1-8-3-6-5-7-2  
Hyd. Lifters Zero Lash  
Dry Lash .060"-.210"  
5th Digit Code H  
Engine Color Turquoise  
Series D383  
Type L383HP  
Comp. Ratio 10.0:1  
Comp. PSI 130-165  
(max. var.) 25

## BATTERY 12v Neg. Grd.

Standard 24MB59 59AH  
Spec. Equip. 27MB70R 70AH  
Cranking Voltage (min) 9.5v  
Starter Draw (cranking) 180-200A (max.)

## CHARGING SYSTEM

Output (min) Standard W/Air Cond.  
Operating Voltage @ 700F 13.7-15.2v 12.7-13.2v  
(measured at battery)

## IDLE

RPM Manual Trans 650 Air Cond. off  
Auto. Trans. (N) 650 Air Cond. off  
Unsnap ball joint connection at accelerator bell crank  
before setting—Adjust to mate socket.

## DWELL (Degrees)

At Idle 28-33  
Variation 2 (lost vac. line disconnected)

## IGNITION TIMING (Degrees)

Dist. Vac. Line Disconnected  
Manual Trans. DC TDC @ Idle RPM  
Auto. Trans. 5 BTDC @ Idle RPM

## IGNITION ADVANCE (Degrees @ 2600 RPM)

Manual Trans. Cent. & Vac. Cent. Only  
Auto. Trans. 44-54 26-30 22-28%

## IDLE MIXTURE

Air Fuel Ratio 14.0:1 (min)

## FUEL PUMP

Pressure 3½-5 PSI @ 500 RPM  
Vol. 1 qt. 30 sec. @ 500 RPM  
Vac. 10" @ 500 RPM  
Filter (disposable element type) in line between fuel pump and carb. Replaces every two years or 24,000 miles.  
Filter (fuel tank) Plastic filter on and at suction tubes.

## SPARK PLUGS

Champion J11Y or J10Y  
Mopar P-3-4P  
Gap .035"  
Torque 30 Ft/Lbs.

## CARBURETOR

Manual Trans. Chrysler-2863841  
Auto. Trans. Chrysler-2863801  
Chrysler-2863801  
Chrysler-2863801

## DISTRIBUTOR

Chrysler 2863801  
Auto. Trans. 2863801  
Manual Trans. 2863801  
Rotation CC  
Spring Tension (oz) 17-20  
Gas (inch) .014-.019  
Vibration (Degrees) 28-33  
Condenser Capacity 2 1 .25-.26µMFD

## MECHANICAL ADVANCE

2863801 Dist. Deg. 2863801 Dist. Deg.  
Dist. RPM 375-525 375-525  
525 0-6% 525 0-6%  
800 11%-13% 760 10-12  
2500 17-19 2500 14%-18%

## VACUUM ADVANCE

In. Vac. Dist. Deg. In. Vac. Dist. Deg.  
5-7% 0 6-7% 0  
12 6-9 12 6-9  
14% 9-12 14% 9-12

## IGNITION COIL (Labels @ 700 RPM)

Chrysler Prestolite 2444242  
Pri. Res 165.179  
Sec. Res 9400-11700  
Test Set Line 8  
Chrysler Essex 2444241  
Pri. Res 141.156  
Sec. Res 9200-10600  
Test Set Line 8  
Ballast Resistor  
Chrysler 2095501 0.506  
Engine Stopped 3.0A  
Idling 1.8A

## IGNITION CURRENT

HI TENSION WIRE RESISTANCE (Labels)  
Coil cable intact (either primary terminal of coil to center contact of dist. cap) - 25,000 max.  
Coil cable removed - 15,000 max.  
Spark Plug cables - 30,000 max.

## SECONDARY RESISTANCE

3.0 max.

## CRANKING CIRCUIT RESISTANCE

Insulated Circuit  
Bat. Pos. Post to Sol. Bat. Term. - 2v  
(Sol. sec. only - 2v)  
(Each connection - 1v)  
Ground Circuit  
Starter Housing to Bat. Neg. Post - 2v  
(Grid cable only - 2v)  
(Each 9rd circuit - 1v)  
(Each connection - 1v)

## STARTER FREE RUNNING CURRENT DRAW

80A max. @ 11v RPM 1925-2600 (max)  
SOLENOID CURRENT DRAW  
Pull in Coil 14.4-16.0A @ 6v  
Hold in Coil 11.5-12.8A @ 6v

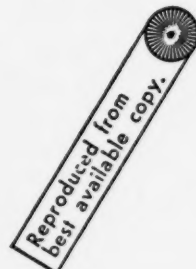


Figure 2-5. Typical Tuneup Guide

Table 2-10. Inspection Procedures

| <u>Item Parameter</u> *             | <u>Procedure</u>                                                                                                                                                                                                                                                                                                          |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2.1 Basic Timing                    | The vacuum advance and retard lines were disconnected and the timing was read on the engine pointer with a timing light.                                                                                                                                                                                                  |
| 2.2 Total Advance                   | Vacuum lines were reconnected and the engine speed held at 2500 rpm. The timing light was adjusted to synchronize with TDC, the ignition scope console indicated the total advance, and the basic timing was subtracted from the meter reading.                                                                           |
| 2.3 Mechanical Advance              | The vacuum lines to the distributor were disconnected and the procedure for 2.2 was repeated.                                                                                                                                                                                                                             |
| 2.4 Vacuum Advance                  | The observed mechanical advance was subtracted from the observed total advance.                                                                                                                                                                                                                                           |
| 2.5 Coil Available Voltage          | The average firing voltage at 1500 rpm, in neutral, as observed on the ignition scope, was recorded.                                                                                                                                                                                                                      |
| 2.6 Plug Required Voltage           | One spark plug wire was disconnected and the firing voltage for that cylinder at 1500 rpm was recorded.                                                                                                                                                                                                                   |
| 2.7 Point Dwell                     | The average dwell was read on the console dwell meter.                                                                                                                                                                                                                                                                    |
| 2.8 Dynamic Compression             | By means of the ignition scope console, each spark plug was individually shorted at 1500 rpm and the console indicated the percent reduction in rpm.                                                                                                                                                                      |
| 3.1 30 mph Performance<br>Diagnosis | The chassis dynamometer was set so that the vehicle speed was 30 mph at 16 in.Hg manifold vacuum. The exhaust %CO concentration was read, the average spark plug firing voltage was observed, and the number of spark plugs misfiring and frequency of misfire were determined as a percentage of total required firings. |

\* Keyed to Table 2-8.



Table 2-10. Inspection Procedures (Cont.)

|                                      |                                                                                                                                                  |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 3.2 45 mph Diagnosis                 | The vehicle was operated at 45 mph at 8 in. Hg manifold vacuum and the observations from 3.1 were repeated.                                      |
| 3.3 60 mph WOT Performance Diagnosis | The vehicle was operated at 60 mph, wide open throttle. The observations from 3.1, except % CO, were repeated.                                   |
| 4.1 Idle Speed                       | The idle rpm was observed on the ignition scope with the transmission either in neutral or drive, as specified by the manufacturer.              |
| 4.2 Idle % CO                        | The idle % CO was recorded.                                                                                                                      |
| 4.3 Manifold Vacuum                  | The manifold vacuum at idle was read with a vacuum gauge.                                                                                        |
| 4.4 Air Cleaner, Angle               | The air cleaner filter element was installed on an AC air cleaner tester and the relative pressure drop was observed on a 0 to 180 degree scale. |
| 4.5 Float Level                      | The float level was measured using the procedure specified in the shop manual.                                                                   |
| 4.6 Heat Riser Valve                 | If there was a heat riser valve it was checked for sticking.                                                                                     |
| 5.1 PCV Performance at Idle          | The crankcase vacuum was measured at the dipstick tube using a vacuum gauge reading in inches of water.                                          |
| 5.2 Air Pump Performance             | The dead head pressure of one of the air pump outlet hoses was read in inches of mercury.                                                        |
| 5.3 Vacuum Leaks                     | The individual vacuum hoses were closed off to check for leaks in the system (see 5.4).                                                          |
| 5.4 Idle Speed                       | The idle rpm was recorded to determine the magnitude of the leakage compared to the idle rpm in 4.1.                                             |

idle % CO readings was 3.5%. Any amount of misfire was unacceptable.

The limit for acceptable variation of dynamic compression was 2% between all cylinders. This was the recommended tolerance given in the ignition scope operating manual.

The equipment required for the parameter survey consisted of conventional diagnostic equipment, an electric chassis dynamometer, and two nondispersive infrared carbon monoxide analyzers. The diagnostic equipment included an Autoscan 4000 Ignition Analyzer, a 0-15 in. Hg pressure gauge, a 0-5 in. H<sub>2</sub>O vacuum gauge, and an AC air cleaner tester. The AC air cleaner tester was a type used in the service trade and indicates a relative degree of restriction. With this type of tester (see Figure 2-6), air flow is induced through the filter element and the pressure drop created is indicated on an arbitrary scale of increasing restriction. The air flow is produced from regulated shop air through an aspirator underneath the filter element. The tester is calibrated by adjusting the shop air flow to produce a calibration setting using a fixed opening to the aspirator system. For this program, a protractor was placed over the pointer to facilitate reading the amount of air cleaner restriction. Figure 2-7 shows actual aspirator system vacuum data plotted against the indicator angular position.

The methods and equipment used in the engine parameter survey provided reliable evaluation of the components and adjustments. While measurement accuracy was not of laboratory quality, the errors were low enough to provide a pass/fail evaluation with a high level of confidence.

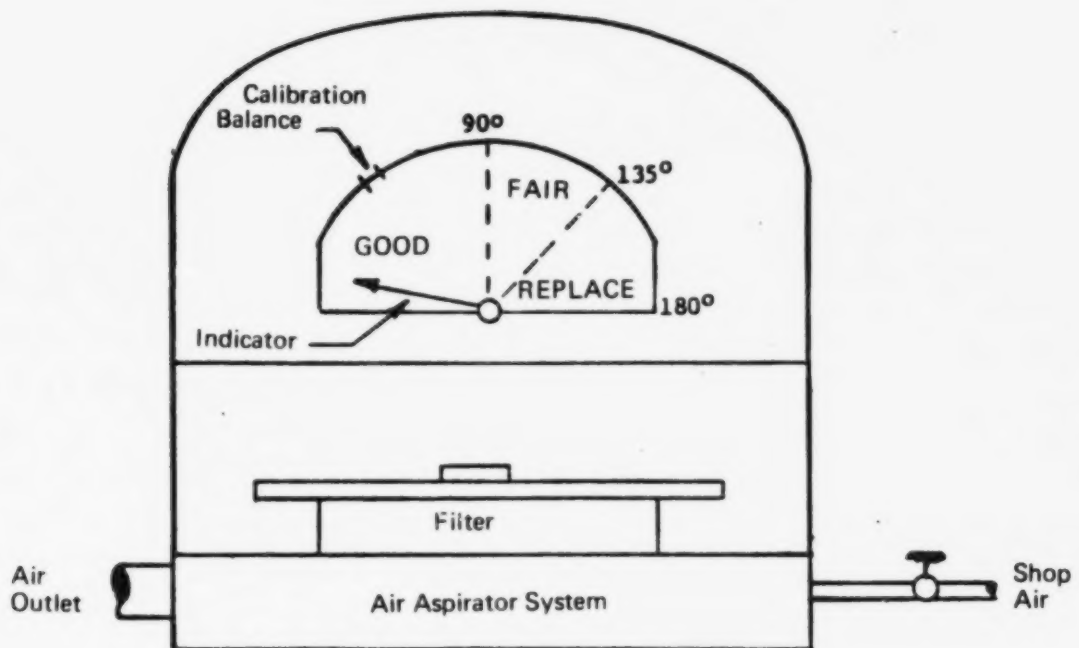


Figure 2-6. AC Air Cleaner Tester

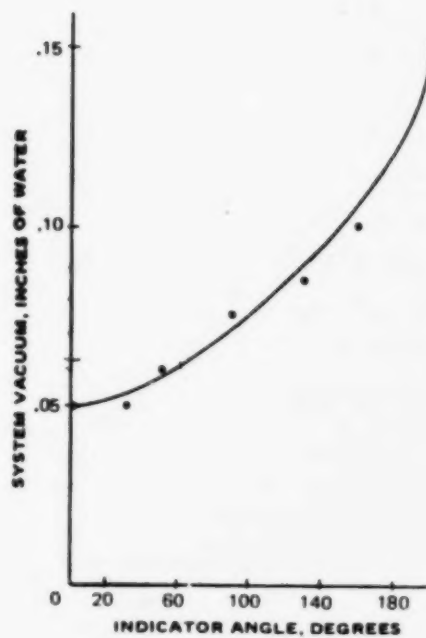


Figure 2-7. Air Cleaner Tester System Vacuum Versus Indicator Angle

### 3. PARAMETER SCREENING EXPERIMENT

An experiment to screen the most frequent and extensive malfunctioned engine parameters was performed. This screening was based on the emission response of representative power trains to simulated engine parameter malfunctions. The diagnostic power of emissions measured under varying engine loads was also investigated. The following subsections discuss the results and experimental procedure applied to develop these data.

#### 3.1 TEST RESULTS AND CONCLUSIONS

The test results and conclusions are presented for two experiments performed to screen engine parameters;

- Orthogonal test evaluation of eleven parameters
- Choke parameter experiment

##### 3.1.1 Screening Experiment

The screening experiment, as previously noted, had as its objective the identification of the most effective procedures and sensitive emission diagnostic modes to be studied in the more definitive experiment.

A complete summary of the statistically reduced data for the three hot cycle emissions (HC, CO and NO) is presented in Tables 3-1 through 3-6. The vehicle descriptions are keyed through the vehicle number and presented in Table 3-7. The summary data are comprised of the emissions change,  $\Delta E$ , that results from a change in parameter level,  $\Delta P$ . The units of  $\Delta E$  for composite (volumetric) emissions is parts per million (ppm) and for mass emissions, grams per mile. These data were abstracted from a more complete data tabulation which may be found in Appendix A. In addition, an effectiveness index, EI, was developed for each of the parameters and is used as a figure of merit for selecting those parameters to be carried into the definitive experiment. This index is essentially the emissions reductions which could be affected when all of the vehicles in the general population have a specific parameter, ( $P_i$ ), restored to its nominal or specification value. The mathematical definition of the index is:

Table 3-1. Summary of Orthogonal Test Data, HC Composite Emission Sensitivity to Malfunction (90% Confidence Level and Above)

Screening Experiment

| Vehicle No.     | Timing <sup>+7</sup> <sub>-10</sub> |        | Misfire <sup>+2.5%</sup> <sub>0</sub> |        | ICO <sup>+20%</sup> <sub>-0.5%</sub> |      | IRPM <sup>+50</sup> <sub>-100</sub> |        | Vacuum Adv. spec <sub>0</sub> |       | Leak <sup>+1cfm</sup> <sub>0</sub> |       |
|-----------------|-------------------------------------|--------|---------------------------------------|--------|--------------------------------------|------|-------------------------------------|--------|-------------------------------|-------|------------------------------------|-------|
|                 | $\Delta E$                          | EI     | $\Delta E$                            | EI     | $\Delta E$                           | EI   | $\Delta E$                          | EI     | $\Delta E$                    | EI    | $\Delta E$                         | EI    |
| 501A            | 137                                 | 7.3    | 486                                   | 66.3   | -158                                 | -168 | -146                                | 6.5    | ---                           | ---   | ---                                | ---   |
| 502             | 246                                 | 13.1   | 472                                   | 64.2   | -137                                 | -204 | ---                                 | ---    | ---                           | ---   | 177                                | 12.2  |
| 503             | ---                                 | ---    | 454                                   | 61.7   | ---                                  | ---  | ---                                 | ---    | ---                           | ---   | 143                                | 9.8   |
| 504A            | 221                                 | 11.7   | 335                                   | 95.7   | ---                                  | ---  | -77                                 | 4.6    | ---                           | ---   | ---                                | ---   |
| 505A            | 103                                 | 5.5    | 314                                   | 83.5   | ---                                  | ---  | ---                                 | ---    | ---                           | ---   | ---                                | ---   |
| 506             | 116                                 | 6.1    | 303                                   | 86.8   | 64                                   | 95   | -140                                | 8.4    | 107                           | -1.8  | -72                                | -3.3  |
| 507             | 246                                 | 13.0   | 273                                   | 72.7   | ---                                  | ---  | -212                                | 12.7   | ---                           | ---   | 132                                | 8.5   |
| 508             | 180                                 | 9.6    | 296                                   | 78.7   | -97                                  | -145 | -71                                 | 4.29   | 107                           | -1.59 | ---                                | ---   |
| 509A            | 280                                 | 14.8   | 264                                   | 70.3   | ---                                  | ---  | -256                                | 15.4   | 58                            | -1.02 | ---                                | ---   |
| 510             | 309                                 | 16.3   | 221                                   | 58.6   | -288                                 | -429 | -217                                | 13.0   | 268                           | -5.63 | 247                                | 13.2  |
| 511             | ---                                 | ---    | 189                                   | 53.9   | ---                                  | ---  | ---                                 | ---    | ---                           | ---   | ---                                | ---   |
| $\bar{X}$ , ppm | 206                                 | (10.8) | 329                                   | (72.0) | -123                                 | -170 | -160                                | (9.27) | 135                           | -2.51 | 125                                | (7.7) |

$\bar{X}$  = mean value of response, all statistically significant vehicles

A = air injection system

$\Delta E$  = change in emission in going from the low to high value of the parameter, ppm

EI =  $(P_i - P_{spec}) \Delta E / \Delta P_i$

Table 3-2. HC Mass Emission Sensitivity to Malfunction  
(90% Confidence Level and Above)

Screening Experiment  
Change in Emission Level,  $\Delta E$ , grams per mile

| Vehicle                                  | Timing <sup>+7</sup> <sub>-10</sub> | Vac Adv <sup>spec</sup> <sub>0</sub> | Pt Res <sup>*</sup> | Misfire <sup>2.5%</sup> <sub>0</sub> | IC <sup>2.0</sup> <sub>0.5</sub> | IRPM <sup>50</sup> <sub>100</sub> | Float <sup>+1/4</sup> <sub>-1/8</sub> | A/C <sup>180</sup> <sub>0</sub> | PCV plug <sup>spec</sup> | Air plug <sup>spec</sup> | Leak <sup>1cfm</sup> <sub>0</sub> |
|------------------------------------------|-------------------------------------|--------------------------------------|---------------------|--------------------------------------|----------------------------------|-----------------------------------|---------------------------------------|---------------------------------|--------------------------|--------------------------|-----------------------------------|
| 501A                                     | ---                                 | ---                                  | 1.18                | 4.44                                 | -2.03                            | ---                               | ---                                   | 2.33                            | ---                      | ---                      | ---                               |
| 502                                      | 1.60                                | -0.67                                | ---                 | 4.97                                 | -1.30                            | ---                               | 1.33                                  | ---                             | ---                      | ---                      | 1.62                              |
| 503                                      | -1.76**                             | ---                                  | ---                 | 4.91                                 | ---                              | ---                               | ---                                   | ---                             | 1.63                     | ---                      | ---                               |
| 504A                                     | 2.05                                | ---                                  | ---                 | 3.70                                 | ---                              | -1.33                             | ---                                   | ---                             | ---                      | 1.24                     | ---                               |
| 505A                                     | 0.66                                | ---                                  | ---                 | 3.15                                 | ---                              | ---                               | ---                                   | ---                             | ---                      | ---                      | ---                               |
| 506                                      | -1.07**                             | ---                                  | ---                 | 3.27                                 | ---                              | -1.16                             | ---                                   | ---                             | ---                      | ---                      | ---                               |
| 507                                      | 1.39                                | ---                                  | ---                 | 3.36                                 | ---                              | -1.62                             | ---                                   | ---                             | ---                      | ---                      | 2.36                              |
| 508                                      | ---                                 | ---                                  | ---                 | 2.91                                 | ---                              | ---                               | ---                                   | ---                             | ---                      | ---                      | ---                               |
| 509A                                     | 1.22                                | ---                                  | ---                 | 2.32                                 | ---                              | -1.92                             | ---                                   | 0.48                            | ---                      | ---                      | ---                               |
| 510                                      | 2.69                                | 1.09                                 | ---                 | 2.28                                 | -2.84                            | -2.96                             | 1.80                                  | ---                             | 0.54                     | 0.87                     | ---                               |
| 511                                      | ---                                 | ---                                  | 0.27                | 1.74                                 | ---                              | -1.03                             | -0.51                                 | ---                             | 2.30                     | ---                      | ---                               |
| $\bar{X}$ $\frac{\text{gms}}{\text{mi}}$ | <u>1.60</u>                         | ---                                  | ---                 | <u>3.37</u>                          | ---                              | <u>-1.67</u>                      | ---                                   | ---                             | <u>1.49</u>              | ---                      | ---                               |

\* Pt. resistance originally expressed as  $\Omega$  impedance, after Vehicle No. 505 expressed as:

$$\frac{\text{Available Primary Kv}}{\text{Required Secondary Kv}} \times 100$$

\*\* Not considered in  $\bar{X}$   
see notes, Table 3-1



Table 3-3. Summary of Orthogonal Test Data  
CO Hot Composite  
(90% Confidence Level and Above)  
Screening Experiment

| Vehicle No.   | IC0, +2%, -0.5% |      | Float, +1/4, -1/8 |       | A/C, 180, 0  |      | PCV, Plug Spec |       | Air Pump, Plug Spec |       | Leak, 1 cfm, 0 |       |
|---------------|-----------------|------|-------------------|-------|--------------|------|----------------|-------|---------------------|-------|----------------|-------|
|               | $\Delta E$ %    | EI % | $\Delta E$ %      | EI %  | $\Delta E$ % | EI % | $\Delta E$ %   | EI %  | $\Delta E$ %        | EI %  | $\Delta E$ %   | EI %  |
| 501           | .575            | .616 | -.827             | -.044 | 0.368        | .081 | ---            | ---   | .554                | .053  | -.648          | -.015 |
| 502           | .428            | .637 | -.561             | -.030 | 1.145        | .252 | .473           | .056  | N/A                 | N/A   | ---            | ---   |
| 503           | .286            | .426 | -.623             | -.033 | 1.741        | .383 | 1.325          | .158  | N/A                 | N/A   | -.468          | -.032 |
| 504           | .434            | .646 | -.300             | -.016 | ---          | ---  | 0.240          | .029  | .290                | .028  | -.188          | -.013 |
| 505           | .249            | .371 | -.286             | -.015 | ---          | ---  | 0.209          | .025  | .291                | .028  | -.129          | -.027 |
| 506           | ---             | ---  | -.825             | -.044 | 0.604        | .143 | 0.31           | .037  | N/A                 | N/A   | ---            | ---   |
| 507           | .623            | .927 | -.522             | -.028 | 0.268        | .070 | 0.383          | .046  | N/A                 | N/A   | -.146          | -.009 |
| 508           | .333            | .495 | -.824             | -.044 | 0.507        | .122 | 0.315          | .037  | N/A                 | N/A   | ---            | ---   |
| 509           | .293            | .436 | -.444             | -.024 | ---          | ---  | 0.706          | .084  | .508                | .049  | ---            | ---   |
| 510           | .565            | .841 | -.321             | -.017 | ---          | ---  | 0.476          | .057  | N/A                 | N/A   | ---            | ---   |
| 511           | .504            | .750 | ---               | ---   | N/A          | N/A  | ---            | ---   | N/A                 | N/A   | ---            | ---   |
| $\bar{X}$ , % | .429            | .614 | -.523             | -.028 | 0.772        | .175 | 0.493          | .0582 | .411                | .0395 | -.363          | -.017 |

See notes, Table 3-1.

Table 3-4. Summary of Orthogonal Test Data  
CO Mass Emission Sensitivity to Malfunction  
(90% Confidence Level and Above)

| Screening Experiment                                  |        |         |        |         |      |      |       |      |      |          |       |  |
|-------------------------------------------------------|--------|---------|--------|---------|------|------|-------|------|------|----------|-------|--|
| Change in Emission Level, $\Delta E$ , grams per mile |        |         |        |         |      |      |       |      |      |          |       |  |
| Vehicle No.                                           | Timing | Vac Adv | Pt Res | Misfire | ICO  | IRPM | Float | A/C  | PCV  | Air pump | Leak  |  |
| 501A                                                  | -16.7  | ---     | ---    | ---     | 16.9 | ---  | -34.6 | 18.0 | ---  | 28.9     | ---   |  |
| 502                                                   | -17.2  | ---     | 3.9    | ---     | 19.0 | ---  | -11.6 | 25.7 | 8.8  | ---      | ---   |  |
| 503                                                   | -69.4  | ---     | ---    | ---     | ---  | ---  | -23.0 | 72.5 | 49.6 | ---      | -22.9 |  |
| 504A                                                  | -21.8  | ---     | ---    | 8.6     | 17.1 | ---  | ---   | 8.3  | 13.6 | 10.5     | ---   |  |
| 505A                                                  | -20.0  | ---     | 4.3    | ---     | ---  | 11.1 | - 7.5 | ---  | 9.9  | 14.4     | ---   |  |
| 506                                                   | -83.2  | -27.1   | ---    | ---     | ---  | ---  | -32.6 | 37.3 | ---  | ---      | ---   |  |
| 507                                                   | ---    | ---     | ---    | ---     | 15.0 | ---  | -13.2 | ---  | ---  | ---      | ---   |  |
| 508                                                   | -29.4  | - 6.5   | ---    | ---     | ---  | ---  | -15.6 | 18.8 | ---  | ---      | ---   |  |
| 509A                                                  | -18.1  | ---     | ---    | ---     | 10.4 | 11.3 | ---   | ---  | 19.9 | 16.7     | ---   |  |
| 510                                                   | ---    | ---     | ---    | ---     | 15.8 | ---  | ---   | ---  | 13.6 | ---      | ---   |  |
| 511                                                   | ---    | ---     | ---    | 6.6     | ---  | ---  | - 7.5 | ---  | ---  | ---      | ---   |  |
| $\bar{X}$ , $\frac{gr}{mi}$                           | -34.5  |         |        |         | 15.7 |      | -18.2 | 30.1 | 19.2 | 17.6     |       |  |

See notes, Table 3-2.

Table 3-5. Summary of Orthogonal Test Data  
 NO Composite Emission Sensitivity to Malfunction  
 Screening Experiment

| Vehicle No.     | Timing     |      | Vacuum Advance |       | Float      |      | PCV        |       |
|-----------------|------------|------|----------------|-------|------------|------|------------|-------|
|                 | $\Delta E$ | EI   | $\Delta E$     | EI    | $\Delta E$ | EI   | $\Delta E$ | EI    |
| 505             | 889        | 47.1 | 243            | -6.5  | 197        | 10.5 | ---        | ---   |
| 506             | 255        | 13.5 | 236            | -3.9  | 151        | 8.06 | ---        | ---   |
| 507             | 524        | 27.8 | 130            | -3.3  | 104        | 5.6  | -190       | -22.7 |
| 508             | 564        | 29.9 | 530            | -7.9  | 178        | 9.5  | -171       | -20.4 |
| 509A            | 412        | 21.8 | 120            | -2.1  | 154        | 8.2  | -247       | -29.4 |
| 510             | 591        | 30.2 | 677            | -14.3 | 128        | 6.9  | -161       | -19.2 |
| $\bar{x}$ , ppm | 536        | 28.4 | 322            | -6.33 | 152        | 8.1  | -192       | -22.9 |

See notes, Table 3-1.

Table 3-6. Summary of Orthogonal Test Data  
 $\text{NO}_x$  Mass Emission Sensitivity to Malfunction  
 (90% Confidence Level and Above)

Screening Experiment  
 Change in Emission Level,  $\Delta E$ , grams per mile

| Vehicle No. | Timing | Vac Adv | Pt Res | Misfire | ICO | IRPM | Float       | A/C   | PCV          | Air   | Leak |
|-------------|--------|---------|--------|---------|-----|------|-------------|-------|--------------|-------|------|
| 501A        | 2.16   | ---     | ---    | ---     | --- | ---  | 1.11        | ---   | -0.75        | ---   | 1.96 |
| 502         | 2.88   | ---     | 0.51   | ---     | --- | ---  | ---         | -1.14 | ---          | ---   | ---  |
| 503         | 1.51   | ---     | ---    | 0.41    | --- | ---  | 0.41        | -1.34 | -0.72        | ---   | ---  |
| 504A        | 2.63   | ---     | ---    | ---     | --- | ---  | ---         | ---   | ---          | -0.39 | ---  |
| 505A        | 3.70   | ---     | -0.48  | 0.80    | --- | 0.86 | ---         | ---   | ---          | -1.08 | ---  |
| 506         | 1.85   | ---     | ---    | ---     | --- | ---  | 0.76        | -0.78 | ---          | ---   | ---  |
| 507         | 2.98   | ---     | ---    | ---     | --- | 0.68 | ---         | ---   | ---          | ---   | ---  |
| 508         | 2.01   | 0.69    | ---    | ---     | --- | ---  | 0.44        | -0.52 | -0.61        | ---   | ---  |
| 509A        | 1.31   | ---     | ---    | ---     | --- | ---  | 0.71        | ---   | -0.93        | ---   | ---  |
| 510         | 2.43   | 1.22    | ---    | ---     | --- | ---  | ---         | ---   | -0.76        | ---   | ---  |
| 511         | 1.14   | ---     | -0.07  | ---     | --- | 0.18 | 0.15        | ---   | ---          | ---   | ---  |
| $\bar{X}$   | 2.23   |         |        |         |     |      | <u>0.59</u> |       | <u>-0.75</u> |       |      |

See notes, Table 3-2.

Table 3-7. Orthogonal Test Program  
Power Train Attributes

| Vehicle No. | Make  | Model-Yr.   | CID  | CARB.  | Mileage | Cold Start Composite Emissions |      |       |      |
|-------------|-------|-------------|------|--------|---------|--------------------------------|------|-------|------|
|             |       |             |      |        |         | As Received                    |      | Tuned |      |
|             |       |             |      |        |         | HC                             | CO   | HC    | CO   |
| 501         | Chev  | 66 Impala   | 327A | Roch 4 | 67880   | 331                            | 1.93 | 258   | 1.14 |
| 502         | Ford  | 68 Custom   | 302  | Ford 2 | 33361   | 268                            | 1.90 | 290   | 1.53 |
| 503         | Dodge | 68 Charger  | 318  | Cart 2 | 36815   | 304                            | 0.69 | 303   | 1.21 |
| 504         | Merc  | 67 Cougar   | 289A | Ford 2 | 24216   | 2299*                          | 1.83 | 354   | 2.26 |
| 505         | Ford  | 66 Mustang  | 200A | Ford 1 | 18008   | 456                            | 1.76 | 318   | 1.35 |
| 506         | Olds  | 68 98       | 455  | Roch 4 | 45760   | 314                            | 1.74 | 452   | 2.76 |
| 507         | Chev  | 68 Malibu   | 327  | Roch 4 | 19128   | 463                            | 3.56 | 219   | 0.99 |
| 508         | Dodge | 66 Polara   | 383  | Stro 2 | 62801   | 333                            | 1.56 | 345   | 1.49 |
| 509         | Chev  | 69 Nova     | 230A | Roch 1 | 13452   | 284                            | 1.75 | 201   | 1.47 |
| 510         | Ford  | 68 Ranchero | 390  | Ford 2 | 18006   | 354                            | 1.45 | 283   | 1.21 |
| 511         | VW    | 68 1500     | 92   | SOLX 1 | 50340   | 1373*                          | 6.94 | 374   | 2.18 |

\* Misfiring vehicle.

$$EI_{ij} = \int_{-\infty}^{\infty} P(P_i) \frac{de_j}{dP_i} dP_i$$

$$= (\overline{P_i - P_{i \text{ spec}}}) \frac{de_j}{dP_i}$$

where:  $EI_{ij}$  = effectiveness index for parameter  $P_i$   
 $P(P_i)$  = probability of finding parameter,  $P_i$ ,  
at level  $dP_i + P_i$  (from engine parameter survey)  
 $de/dP_i$  = change in emission/change in parameter level  
(from orthogonal screening experiment)

Only those values of  $\Delta E$  and  $EI$  which were found to be statistically significant at the 90% confidence level are shown. The average value of  $\Delta E$  and  $EI$  are shown at the bottom of the respective parameter columns.

#### HC Emissions Response (Tables 3-1 and 3-2)

The  $EI$  values indicate that the most effective parameters to maintain for HC emission control are misfire, idle timing, leak rate and idle rpm. These values are highlighted by circles, positive values indicating emission decreases. As stated, the data indicated that it might be effective to maintain manifold leak rate, however, only five vehicles appeared to be responsive to the malfunction. The response of vehicle 510 to this malfunction is particularly spurious, the  $\Delta E$  value being 2.0 times larger than the average value. The HC emission sensitivity to the most influential engine parameters ranged between  $\pm 50\%$  of the mean of all statistically significant vehicle responses. The most anomalous results are the responses of HC to idle CO, particularly for vehicle 510. Response values of 20% of those actually measured would normally be anticipated (see References 1 and 2). A partial explanation of this is the fact that, in reality, HC's usually respond in a very highly nonlinear fashion to idle CO changes. As this experiment was run at two levels of the parameters, the HC emission response is overestimated. Vehicle HC emissions were not found to be very sensitive to increased point resistance (available to required voltage), air cleaner clogging, carburetor float level, or positive crankcase ventilation gross restrictions.



The HC mass emissions substantiate these general conclusions and the general ranking of parameter sensitivity, Table 3-2. Both leak rate and idle CO effects on HC mass emission are substantially reduced relative to their equivalent composite values, as are the number of statistically significant occurrences.

#### CO Emissions Response (Tables 3-3 and 3-4)

The most effective engine parameters to be maintained to control CO emissions as reflected by the value of the effectiveness index are idle CO, air cleaner, PCV, and air injection with the latter two significantly reduced based on their composite values. Both manifold leak rate and float level have low, negative influences on emission levels. The basic response to float level is indicated to be negative relative to an increasing fuel level in the bowl. That is, the additional head caused by fuel level results in fuel enriched carburetion and, hence, increased (negative changes) CO. Retarded timing was found to have a moderate to substantial increasing influence in CO composite and mass emissions, respectively, contrary to its effect on HC and NO. None of the ignition related parameters were found to affect CO.

#### NO Emissions Response (Tables 3-5 and 3-6)

The most significant parameters affecting NO are basic timing and float level. Those malfunctions which tend to enrich carburetion effected moderate reductions in NO, presumably because of peak combustion temperature reductions. A disconnected vacuum advance essentially retards the spark under moderate acceleration and cruise conditions and results in a decrease in NO emissions. This decrease varied considerably from vehicle to vehicle for composite values; decrements ranged from  $\pm 20\%$  of the average vehicle value. Surprisingly, vacuum advance had a negligible influence on mass weighted emissions. None of the other ignition or induction related parameters appeared to have a significant impact on NO emissions.

In summary, the following conclusions resulted:

- The most effective parameters (as measured by the effectiveness index) to maintain in an enforced program are the idle adjustments of F/A ratio, timing, and rpm; the secondary ignition system (spark plugs and secondary wiring), and the induction system components of air cleaner, PCV, and air injection system on vehicles so equipped.
- Generally, both composite and mass emissions respond equivalently to the engine parameters evaluated.
- Float level and vacuum advance have strong effects on CO and NO emissions, respectively, although their malfunction frequencies are such that they would not have a significant impact on an inspection/maintenance program.

#### Emission Diagnostic Signatures

Thirty-three diagnostic modes were concurrently evaluated in the orthogonal experiment. Emission responses were obtained which are similar to those for the composite and mass emissions. Modes were sought which are significantly more selective to one class of malfunction (i.e., engine subsystem) or to specific components or adjustments.

Typical emission responses to the range of engine malfunctions simulated in the experiment are shown in Tables 3-8 through 3-14. Modes are grouped by degree of engine loading (closed throttle, low load, medium load, and high load). It should be noted that certain malfunctions such as PCV, air pump, and air cleaner restrictions were set at their extremes, nominal and inoperative, while the field they will be in varying states of deterioration. Therefore, emission responses to these parameters would generally be less than those shown.

HC emission response to parameter levels are presented in Tables 3-8 through 3-10 for typical test vehicles. Again, only those emission responses indicated to be at the 90% confidence level or above are shown. As with the composite emissions, misfire and timing have the strongest effects

on HC in the various modes. For vehicles equipped with an air injection system, malfunctioning of this system also significantly affects mode emissions. All parameters but misfire tend to have diminishing effects on HC emissions with increasing load. This would suggest that a highly loaded mode would be least confounded for making a misfire diagnosis. It was also shown in the parameter survey study, Section 2, that increasing load resulted in more frequent misfiring. It is significant to note the strong influence of timing through all of the modes.

Typical CO mode emission responses to parameters are shown in Tables 3-11 through 3-14. The lower loaded modes generally reveal idle CO maladjustments. These may be confounded by other induction system related malfunctions, particularly air injection system, PCV and severely clogged air cleaners. Air cleaner influences generally become progressively stronger with load, thus suggesting that a highly loaded mode CO emission measurement would be most selective in diagnosing this malfunction. This is due to the progressively higher pressure drop across the element giving rise to sub-atmospheric pressures within the carburetor intake. Internally vented carburetor bowls are suspected of responding to this pressure, effectively raising the fuel level in a manner similar to a float maladjustment. There is also the possibility that the reduced air flow affects carburetor fuel metering but this does not explain why some vehicles fail to respond to air cleaner blockage.

In order to assess whether parts of an acceleration mode have more diagnostic content than others, several of these modes were segregated into three equal parts. A typical result is shown in Table 3-15 for the 2 and 3 mph/sec, 0-60 mph modes. The two parameters most sensitive to increasing acceleration load are basic timing and air cleaner restriction. There appears to be no substantial difference between modes using different rates of acceleration.

Fast idle modes, 1500 and 2500 rpm, were also evaluated. These results showed no significant diagnostic content not already in the idle mode. There is an indication that CO emissions may be more sensitive to air injection system malfunctions in this mode.

The above discussion may be summarized as follows:

- Within the loaded mode group, all modes tend to have the same response to malfunction.
- The low and moderately loaded modes for the CO emissions are sensitive to induction system type malfunctions, such as float setting, air leak, air cleaner, and PCV, although basic timing can sometimes confound the diagnosis.
- For air injection controlled vehicles, a malfunction of this device can confound a CO diagnosis for idle adjustment in the closed throttle modes or induction system malfunctions at load.
- The fast idle modes (1500 and 2500 rpm) are not substantially different from the closed throttle modes in diagnostic power.
- Closed throttle HC emissions will generally diagnose maladjusted idle rpm and timing, although an air injection system malfunction on vehicles so equipped will confound the diagnosis.
- Basic timing dramatically affects NO emissions under any loaded condition and is the only diagnostic mode selective to a specific malfunction.
- Intermittent misfire greater than 2.5% of total firings will predominate over most other malfunctions simulated in all modes for HC emissions.

Table 3-8. Diagnostic Mode HC Emissions Sensitivity to Malfunction, Vehicle 506

| Mode*           | Screening Experiment<br>Change in Emission $\Delta E$ , ppm |        |      |      |     |
|-----------------|-------------------------------------------------------------|--------|------|------|-----|
|                 | Misfire                                                     | Timing | Leak | RPM  | IC0 |
| Idle (F)        | 81                                                          | 181    | ---  | -165 | --- |
| Idle (1)        | ---                                                         | 238    | ---  | -301 | --- |
| Idle (11)       | 112                                                         | 159    | ---  | -159 | 106 |
| Idle (27)       | ---                                                         | 147    | 99   | -188 | 106 |
| 30-15 (F)       | 168                                                         | 141    | ---  | -249 | 250 |
| 50-20 (F)       | ---                                                         | ---    | ---  | -319 | 253 |
| 30F (F)         | 174                                                         | 43     | ---  | ---  | --- |
| 24C (28)        | 181                                                         | 42     | ---  | ---  | 20  |
| 30A (19)        | 188                                                         | 46     | ---  | ---  | --- |
| 30S (32)        | 194                                                         | 38     | ---  | ---  | --- |
| +2 mph/sec (13) | 191                                                         | 53     | ---  | ---  | --- |
| 40C (29)        | 187                                                         | ---    | ---  | -21  | --- |
| 45S (31)        | 196                                                         | ---    | ---  | ---  | --- |
| 0-25 (F)        | 152                                                         | 89     | ---  | -59  | --- |
| 15-30 (F)       | 176                                                         | 56     | ---  | ---  | 22  |
| 0-30A (18)      | 163                                                         | 80     | ---  | -75  | 60  |
| 60S (30)        | 217                                                         | 69     | ---  | ---  | --- |
| 60P (25)        | 181                                                         | ---    | ---  | ---  | --- |
| +3 mph/sec (7)  | 187                                                         | 64     | ---  | ---  | --- |

\* Numbers in parentheses correspond to mode type and location shown in Figure 3-7, "F" designates Federal 7 mode.



Table 3-9. Diagnostic Mode HC Sensitivity to Malfunction, Vehicle 508

Screening Experiment  
Change in Emission  $\Delta E$ , ppm

| Mode       | Misfire | Timing | Leak | RPM  | IC0     | Float | A/C | PCV |
|------------|---------|--------|------|------|---------|-------|-----|-----|
| Idle F     | 298     | 154    | ---  | ---  | ---     | ---   | --- | --- |
| Idle 11    | 392     | 237    | ---  | -145 | 168.    | ---   | --- | --- |
| Idle 27    | 324     | 128    | ---  | -56  | 79.     | ---   | --- | --- |
| 30-15      | ---     | 386    | ---  | ---  | 389.    | -409  | --- | --- |
| 50-20      | 311     | 363    | ---  | -780 | ---     | ---   | 228 | 294 |
| 30F        | 313     | 71     | ---  | ---  | ---     | -70   | 40  | --- |
| 24C        | 308     | 64     | ---  | ---  | ---     | -72   | 35  | 36  |
| 30A        | 335     | 100    | ---  | -53. | 46.     | -75   | 86  | --- |
| +2 mph/sec | 379     | 148    | ---  | -88  | 52.     | ---   | 67  | --- |
| 40C        | 321     | 46     | ---  | ---  | ---     | -47   | 51  | --- |
| 0-25       | 309     | 110    | ---  | ---  | ---     | -36   | --- | --- |
| 15-30      | 301     | 94     | ---  | ---  | ---     | -48   | --- | 27  |
| 0-30A      | 369     | 138    | ---  | -91  | 81.     | -66   | 92  | --- |
| 60S        | 359     | 119    | ---  | ---  | ---     | -30   | 37  | --- |
| 60P        | 328     | 77     | ---  | ---  | 33.0214 | -44   | 73  | --- |
| +3 mph/sec | 332     | 95     | ---  | ---  | ---     | -27   | 33  | 28  |



Table 3-10. Diagnostic Mode HC Sensitivity to Malfunction, Vehicle 509

Change in Emission  $\Delta E$ , ppm

| Mode       | Misfire | A/C | ICO | Float  | RPM      | Air Inj | Leak   | Timing | PCV     |
|------------|---------|-----|-----|--------|----------|---------|--------|--------|---------|
| Idle F     | 233.07  | --- | --- | ---    | -235.80  | 160.00  | ---    | 214.82 | ---     |
| Idle 1     | 233.60  | --- | --- | ---    | -162.96  | ---     | ---    | 177.70 | ---     |
| Idle 11    | 233.30  | --- | --- | ---    | -255.47  | 162.56  | ---    | 236.67 | ---     |
| Idle 27    | 220.99  | --- | --- | ---    | -188.15  | 140.06  | ---    | 191.39 | ---     |
| 50-20      | ---     | --- | --- | ---    | -1605.44 | 653.31  | ---    | 935.79 | ---     |
| 60-20      | 773.68  | --- | --- | ---    | -1402.89 | 712.98  | 302.57 | ---    | -413.57 |
| 30F        | 247.02  | --- | --- | -49.93 | -55.85   | 115.69  | ---    | 87.29  | ---     |
| 24C        | 245.51  | --- | --- | ---    | ---      | 91.40   | ---    | 122.05 | ---     |
| 30A        | 247.53  | --- | --- | -62.08 | -73.74   | 100.05  | ---    | 91.03  | ---     |
| +2 mph/sec | 257.08  | --- | --- | ---    | -53.21   | 79.96   | ---    | 114.67 | ---     |
| 40C        | 257.37  | --- | --- | ---    | ---      | 117.34  | ---    | 127.71 | ---     |
| 0-25       | 237.03  | --- | --- | ---    | -124.11  | 151.62  | ---    | 159.09 | ---     |
| 15-30      | 243.56  | --- | --- | ---    | -52.61   | 113.74  | ---    | 136.24 | 60.33   |
| 0-30A      | 240.45  | --- | --- | ---    | -158.15  | 123.91  | ---    | 126.72 | ---     |
| 60S        | 230.77  | --- | --- | ---    | -39.88   | 82.60   | ---    | 93.48  | ---     |
| 60P        | ---     | --- | --- | ---    | ---      | ---     | ---    | ---    | ---     |
| +3 mph/sec | 287.71  | --- | --- | ---    | ---      | ---     | ---    | ---    | ---     |

Table 3-11. Diagnostic Mode CO Emission Sensitivity to Malfunction, Vehicle 503  
Change in Emission  $\Delta E$ , %

| Mode       | Leak  | IC0  | Float | A/C   | PCV   |
|------------|-------|------|-------|-------|-------|
| Idle F     | ---   | 2.11 | ---   | ---   | 0.62  |
| Idle 1     | ---   | 1.49 | ---   | 0.71  | 0.63  |
| Idle 11    | ---   | 2.21 | ---   | ---   | 0.98  |
| Idle 27    | ---   | 2.17 | ---   | 0.52  | 0.84  |
| 30-15      | ---   | 2.00 | ---   | 0.83  | 0.58  |
| 50-20      | ---   | 2.12 | ---   | -0.37 | 0.67  |
| 30F        | ---   | ---  | ---   | 2.65  | 1.66  |
| 24C        | ---   | ---  | ---   | 1.70  | 1.25  |
| 30A        | ---   | ---  | ---   | 2.08  | ---   |
| 30S        | ---   | ---  | ---   | 2.17  | ---   |
| +2 mph/sec | -0.85 | ---  | ---   | 3.58  | 1.09  |
| 40C        | ---   | ---  | ---   | 3.01  | 1.76  |
| 45S        | ---   | ---  | ---   | 2.97  | ---   |
| 0-25       | -0.51 | ---  | -0.76 | 1.90  | 1.57  |
| 15-30      | -0.86 | ---  | 2.31  | 1.71  | -0.86 |
| 0-30A      | -0.48 | 0.46 | -0.60 | 1.76  | 1.34  |
| 60S        | ---   | ---  | ---   | 3.06  | ---   |
| 60P        | ---   | ---  | ---   | 3.51  | 2.05  |
| +3 mph/sec | ---   | ---  | ---   | 4.08  | ---   |

Table 3-12. Diagnostic Mode CO Sensitivity to Malfunction, Vehicle 508

Screening Experiment  
Change in Emission  $\Delta E$ , %

| Mode       | Misfire | Timing | Leak | RPM  | ICO  | Float | A/C  | PCV   |
|------------|---------|--------|------|------|------|-------|------|-------|
| Idle F     | ---     | ---    | ---  | ---  | 2.29 | ---   | 0.55 | ---   |
| Idle 11    | ---     | ---    | ---  | ---  | 2.88 | ---   | ---  | ---   |
| Idle 27    | ---     | ---    | ---  | 0.38 | 2.75 | ---   | 0.57 | ---   |
| 30-15      | ---     | ---    | ---  | ---  | 1.59 | ---   | 0.53 | -0.42 |
| 50-20      | ---     | ---    | ---  | ---  | 1.77 | ---   | 0.75 | ---   |
| 30F        | ---     | -0.61  | ---  | ---  | ---  | ---   | ---  | ---   |
| 24C        | ---     | -0.93  | ---  | ---  | ---  | -0.99 | ---  | 0.68  |
| 30A        | ---     | ---    | ---  | ---  | ---  | -0.63 | ---  | ---   |
| +2 mph/sec | ---     | -1.37  | ---  | ---  | ---  | -0.51 | 0.65 | ---   |
| 40C        | ---     | -2.78  | ---  | ---  | ---  | ---   | 1.47 | ---   |
| 0-25       | ---     | -0.81  | ---  | ---  | ---  | -0.94 | 0.58 | ---   |
| 15-30      | ---     | -0.89  | ---  | ---  | ---  | -0.98 | ---  | 0.55  |
| 0-30A      | ---     | -0.79  | ---  | ---  | ---  | ---   | ---  | ---   |
| 60S        | ---     | ---    | ---  | ---  | ---  | ---   | 0.73 | ---   |
| 60P        | ---     | ---    | ---  | ---  | 0.72 | ---   | 1.16 | 0.98  |
| +3 mph/sec | ---     | -0.97  | ---  | ---  | ---  | -0.78 | 0.84 | ---   |

Table 3-13. Diagnostic Mode CO Emission Sensitivity to Malfunction, Vehicle 509  
Change in Emission  $\Delta E$ , %

| Mode        | Misfire | A/C  | IC0  | Float | RPM  | Air Inj | Leak | Timing | PCV  |
|-------------|---------|------|------|-------|------|---------|------|--------|------|
| Idle F      | ---     | ---  | 1.49 | ---   | ---  | 1.40    | ---  | ---    | ---  |
| Idle 1      | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| Idle 11     | ---     | ---  | 1.34 | ---   | ---  | 1.20    | ---  | ---    | ---  |
| Idle 27     | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| 50-20       | ---     | ---  | 1.60 | ---   | ---  | 1.54    | ---  | ---    | ---  |
| 60-20-2 m/s | ---     | ---  | 0.87 | ---   | ---  | 1.56    | ---  | ---    | ---  |
| 30F         | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| 24C         | ---     | ---  | ---  | -0.53 | ---  | ---     | ---  | -0.81  | 0.88 |
| 30A         | ---     | ---  | ---  | -0.59 | ---  | 0.47    | ---  | ---    | 0.34 |
| +2 mph/sec  | ---     | ---  | ---  | -0.98 | 0.72 | 0.83    | ---  | -1.67  | 0.86 |
| 40C         | ---     | 1.06 | ---  | ---   | ---  | 1.54    | ---  | -1.50  | ---  |
| 0-25        | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| 15-30       | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| 0-30A       | ---     | ---  | ---  | -0.46 | 0.43 | 0.82    | ---  | -0.51  | 0.89 |
| 60S         | ---     | ---  | ---  | ---   | ---  | ---     | ---  | ---    | ---  |
| 60P         | ---     | ---  | ---  | ---   | ---  | 0.18    | ---  | ---    | ---  |
| +3 mph/sec  | ---     | 1.20 | ---  | ---   | ---  | 1.59    | ---  | ---    | ---  |

Table 3-14. Diagnostic Mode CO Sensitivity to Malfunction, Vehicle 510  
Change in Emission  $\Delta E$ , %

| Mode       | Misfire | Timing | Leak   | RPM | IC0  | Float | A/C  | PCV   |
|------------|---------|--------|--------|-----|------|-------|------|-------|
| Idle F     | ---     | ---    | ---    | --- | 2.28 | ---   | ---  | ---   |
| Idle I     | -0.367  | ---    | ---    | --- | 2.25 | ---   | ---  | ---   |
| Idle 11    | ---     | ---    | ---    | --- | 2.65 | ---   | ---  | ---   |
| Idle 27    | ---     | ---    | ---    | --- | ---  | ---   | ---  | ---   |
| 30-15      | ---     | ---    | ---    | --- | 2.26 | ---   | ---  | ---   |
| 50-20      | ---     | ---    | -0.253 | --- | 2.13 | ---   | ---  | -0.29 |
| 30F        | ---     | ---    | ---    | --- | ---  | -0.37 | ---  | 0.39  |
| 24C        | ---     | ---    | ---    | --- | ---  | -0.38 | ---  | 0.51  |
| 30A        | ---     | ---    | ---    | --- | ---  | -0.40 | ---  | 0.45  |
| 30S        | ---     | ---    | ---    | --- | ---  | ---   | ---  | ---   |
| +2 mph/sec | ---     | -1.56  | ---    | --- | ---  | ---   | 1.05 | ---   |
| 40C        | ---     | ---    | ---    | --- | ---  | -0.33 | ---  | 0.51  |
| 45S        | ---     | ---    | ---    | --- | ---  | ---   | ---  | ---   |
| 0-25F      | ---     | ---    | ---    | --- | 0.52 | 0.37  | ---  | 0.59  |
| 15-30F     | ---     | ---    | ---    | --- | 0.30 | -0.49 | ---  | 0.67  |
| 0-30A      | ---     | ---    | ---    | --- | 0.41 | -0.37 | ---  | 0.55  |
| 60S        | ---     | ---    | ---    | --- | ---  | -0.65 | 2.17 | 0.70  |
| 60P        | ---     | 0.29   | ---    | --- | ---  | -0.36 | ---  | 0.55  |
| +3 mph/sec | ---     | ---    | ---    | --- | ---  | ---   | 2.16 | 0.75  |
|            |         |        |        |     |      | -0.25 | ---  | 0.30  |
|            |         |        |        |     |      | -0.32 | ---  | 0.56  |

Table 3-15. Sensitivity of Parts of Acceleration Modes to Malfunctions, Vehicle 503

Change in Emission,  $\Delta E$

|            |               | HC Misfire<br>(ppm) | CO Timing<br>(%) | CO A/C<br>(%) | CO PCV<br>(%) |
|------------|---------------|---------------------|------------------|---------------|---------------|
| +3 mph/sec | L = 0-20 mph  | 212                 | -0.46            | 0.88          | 0.77          |
|            | M = 20-40 mph | 260                 | -0.95            | 1.74          | 0.63          |
|            | H = 40-60 mph | 251                 | -0.83            | 2.03          | ---           |
| +2 mph/sec | L = 0-20 mph  | 213                 | -0.40            | 0.77          | 0.85          |
|            | M = 20-40 mph | 258                 | -0.92            | 1.37          | 0.74          |
|            | H = 40-60 mph | 272                 | -1.31            | 1.79          | 0.54          |



### 3.1.2 Choke Parameter Experiment

Two commonly malfunctioning and maladjusted choke parameters, choke blade setting and heat riser valve, were investigated as a subexperiment. The complete Federal emissions test is required for this determination as the choke is only on below approximately a 100°F block temperature. The Federal emissions of these tests were statistically evaluated and the results are presented in Table 3-16 for both Federal composite and mass emissions. Slopes with "F" ratios indicating a confidence level of 90% or greater are starred. The results indicate that:

- There is a wide variability in the data as indicated by the low statistical significance on the majority of the tests.
- Mass emissions are more highly correlated to these malfunctions than composites.
- General trends are correct, closing the choke results in increasing (positive) HC and CO emissions on 80% of the vehicles; failed open heat riser valves result in increasing (negative) HC and CO emissions on 70% of the vehicles.
- The influence of these adjustments varies considerably from car to car.
- Heat riser valve position appears to have the predominant effect on composite emissions while choke blade has the predominant effect on mass emissions.

Some of the difficulties in the data may be seen in the plots of emissions versus choke blade setting for the two levels of heat riser valve position, Figures 3-1 through 3-6. The emissions responses at both levels of the heat riser valve are seen to be quite different, indicating substantial interactions between parameters may be occurring. The rich (most closed) choke blade setting is extremely anomalous; slopes at this point at the two levels of heat riser valve position having opposite slope signs.

The average effects of making choke adjustments were estimated by averaging the full data set, contrary to the screening test where only statistically significant data were used. These results seem to indicate the most cost-effective choke maintenance would be to free heat riser valves. The effectiveness index for this treatment yields values of 10 ppm and 0.05% for HC and CO, respectively.

Table 3-16. Emission Response to Choke Parameters

HC

|           | Composite Emissions Change |                             |                  |                             | Mass Emissions Change |                |                  |                |
|-----------|----------------------------|-----------------------------|------------------|-----------------------------|-----------------------|----------------|------------------|----------------|
|           | Heat<br>F Ratio            | Riser<br>Slope <sup>2</sup> | Choke<br>F Ratio | Blade<br>Slope <sup>1</sup> | Heat<br>F Ratio       | Riser<br>Slope | Choke<br>F Ratio | Blade<br>Slope |
| 501       | 5.94                       | -47.3                       | 0.46             | -08.8                       | 0.24                  | -0.60          | 0.72             | 0.56           |
| 502       | 0.21                       | 6.7                         | 0.95             | 12.3                        | 0.68                  | -0.50          | 2.80             | 0.85           |
| 503       | 1.27                       | -303.0                      | 1.20             | 236.3                       | 0.97                  | -2.54          | 0.88             | 2.09           |
| 504       | 11.13                      | 58.0*                       | 0.68             | 12.3                        | 11.43                 | 1.43*          | 15.14            | 1.31*          |
| 505       | 0.01                       | 3.3                         | 1.34             | 41.0                        | 1.03                  | 0.69           | 3.46             | -0.46          |
| 506       | 1.09                       | -132.7                      | 0.25             | 14.3                        | 6.13                  | -1.84*         | 1.55             | 0.03           |
| 507       | 0.96                       | 26.3                        | 1.19             | 24.5                        | 0.02                  | 0.06           | 2.03             | 0.59           |
| 508       | 0.54                       | -190.7                      | 0.79             | 7.0                         | 6.07                  | -0.36          | 6.23             | -0.12*         |
| 509       | 7.42                       | -100.0*                     | 4.06             | 41.5                        | 9.93                  | -1.83*         | 1.30             | 0.05           |
| 510       | 1.45                       | 102.7                       | 2.26             | -70.8                       | 6.94                  | 2.09*          | 1.07             | -0.39          |
| 511       | 1.98                       | -96.3                       | 0.17             | -23.0                       | 1.08                  | -0.54          | 0.65             | 0.06           |
| $\bar{x}$ |                            | -41.3                       | >                | 26.0                        |                       | -0.35          | <                | 0.42           |

CO

|           |      |       |       |       |      |         |       |        |
|-----------|------|-------|-------|-------|------|---------|-------|--------|
| 501       | 1.09 | -0.82 | 0.01  | 0.04  | 0.47 | -18.17  | 0.10  | 2.25   |
| 502       | 3.05 | -0.14 | 15.70 | 0.28* | 2.01 | 4.50    | 42.02 | 16.60* |
| 503       | 1.59 | -0.43 | 2.28  | 0.45  | 0.09 | -5.50   | 1.56  | 14.83  |
| 504       | 1.62 | 0.23  | 6.58  | 0.37* | 1.55 | 10.70   | 8.61  | 21.28* |
| 505       | 0.78 | -0.21 | 0.68  | -0.16 | 0.40 | -0.60   | 48.69 | -2.10* |
| 506       | 3.99 | -0.21 | 4.93  | 0.05  | 5.97 | -11.37* | 0.16  | -0.10  |
| 507       | 0.04 | -0.03 | 2.37  | 0.19  | 0.50 | -8.80   | 0.78  | 8.93   |
| 508       | 1.91 | 0.27  | 0.94  | 0.10  | 0.73 | 15.70   | 1.11  | -0.03  |
| 509       | 0.12 | 0.07  | 0.09  | 0.05  | 0.44 | -3.57   | 0.04  | 0.63   |
| 510       | 0.81 | -0.15 | 2.71  | 0.10  | 3.69 | 12.07   | 3.80  | 10.45  |
| 511       | 1.86 | -1.09 | 1.57  | -0.11 | 1.03 | -11.63  | 1.41  | 1.10   |
| $\bar{x}$ |      | -0.23 | >     | 0.12  |      | -1.51   | <     | 6.68   |

<sup>1</sup>Choke blade slope based on increasing closure.<sup>2</sup>Heat riser slope is difference between nominal and fail open condition.

\* Statistically significant at the 90% confidence level.

VEHICLE EMISSION RESPONSE TO CHOKE  
ADJUSTMENT AND MALFUNCTIONS  
VEHICLE 504  
COLD START TESTS

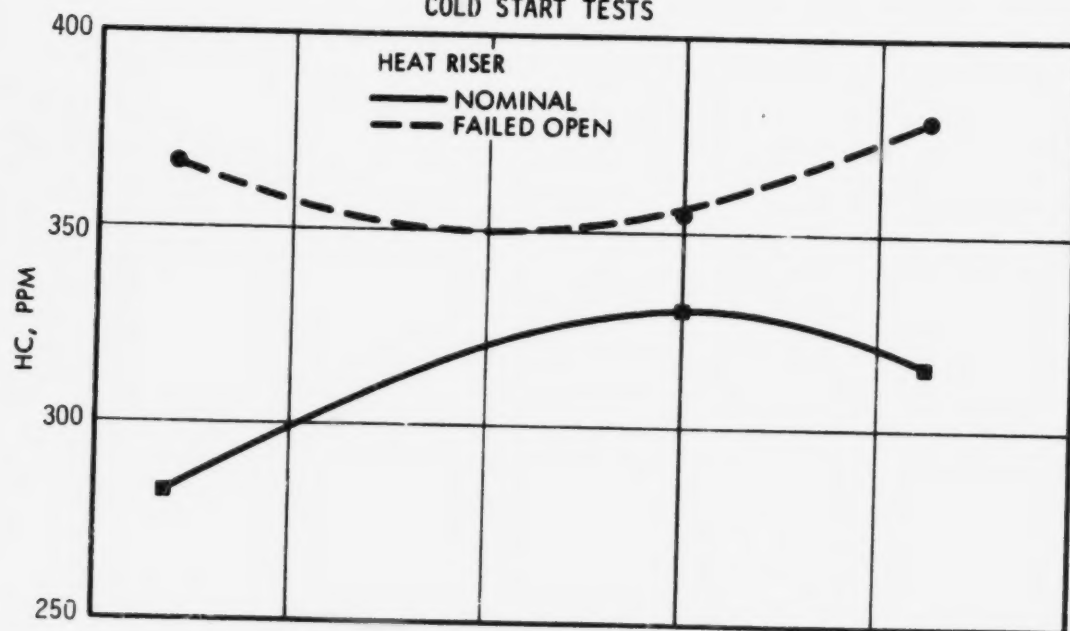


Figure 3-1. HC Emission Response

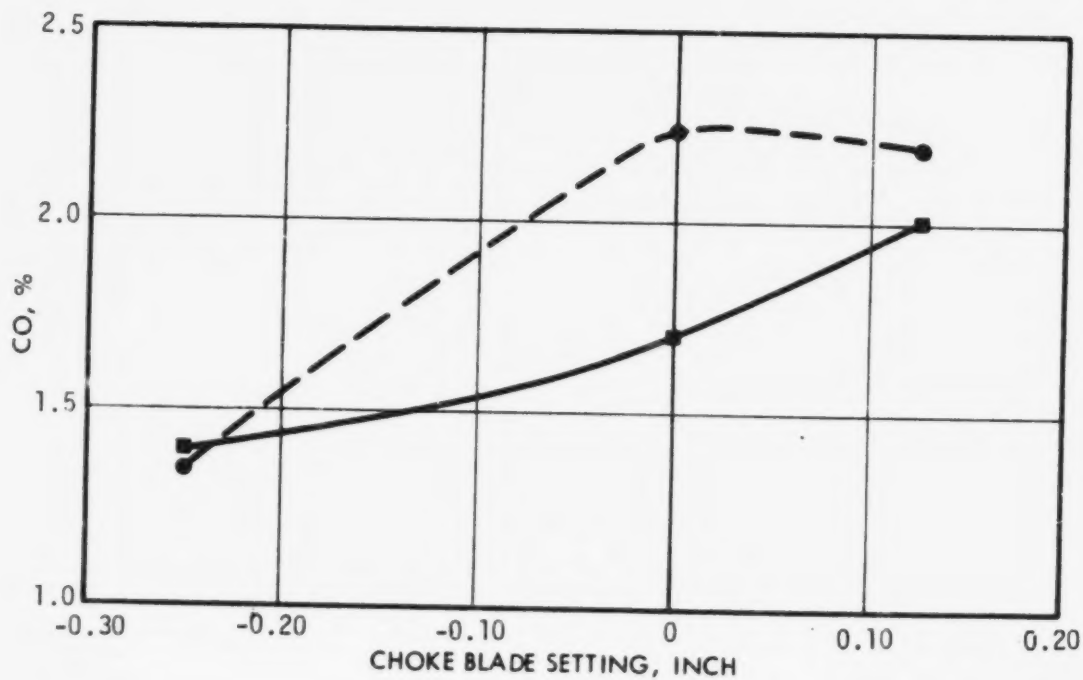


Figure 3-2. CO Emission Response

VEHICLE EMISSION RESPONSE TO CHOKE  
ADJUSTMENT AND MALFUNCTIONS  
VEHICLE 507  
COLD START TESTS

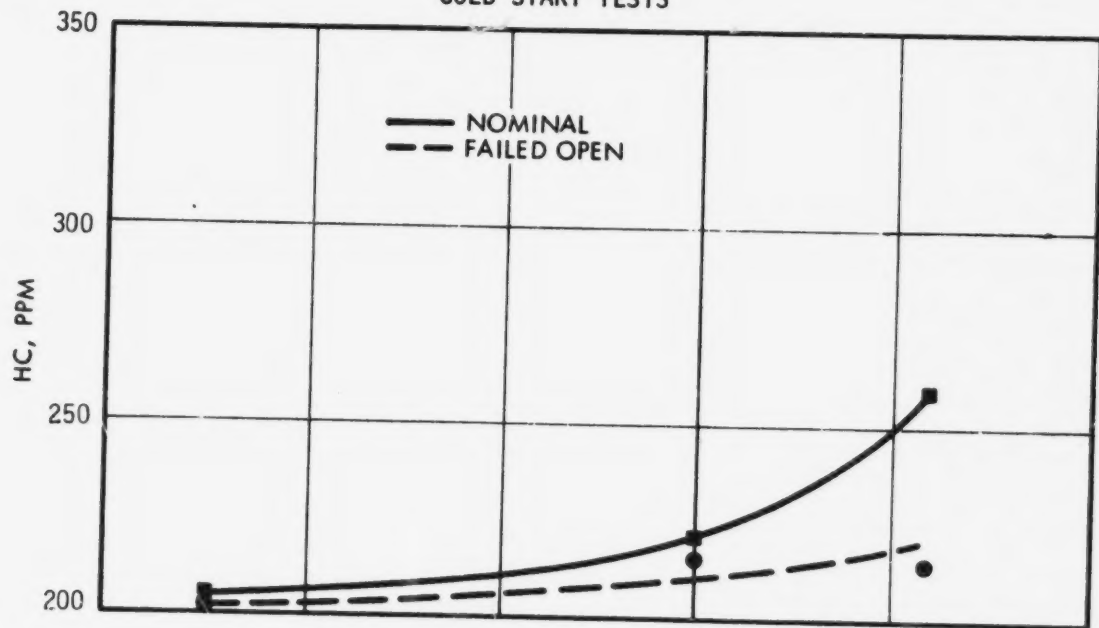


Figure 3-3. HC Emission Response

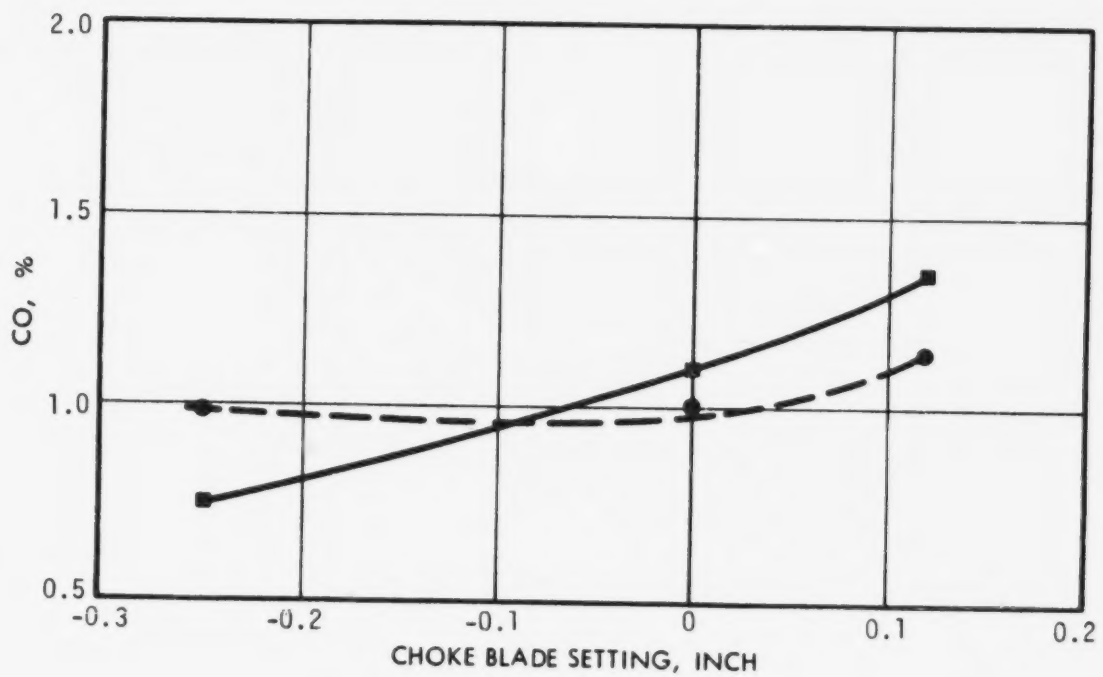


Figure 3-4. CO Emission Response

VEHICLE EMISSION RESPONSE TO CHOKE  
ADJUSTMENT AND MALFUNCTIONS  
VEHICLE 508  
COLD START TESTS

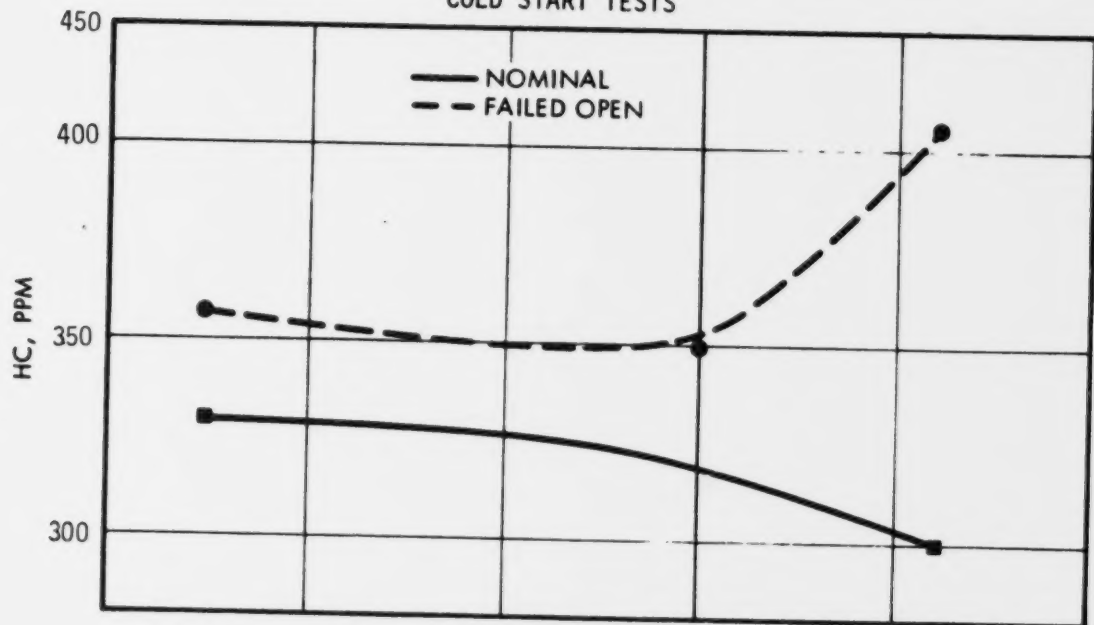


Figure 3-5. HC Emission Response

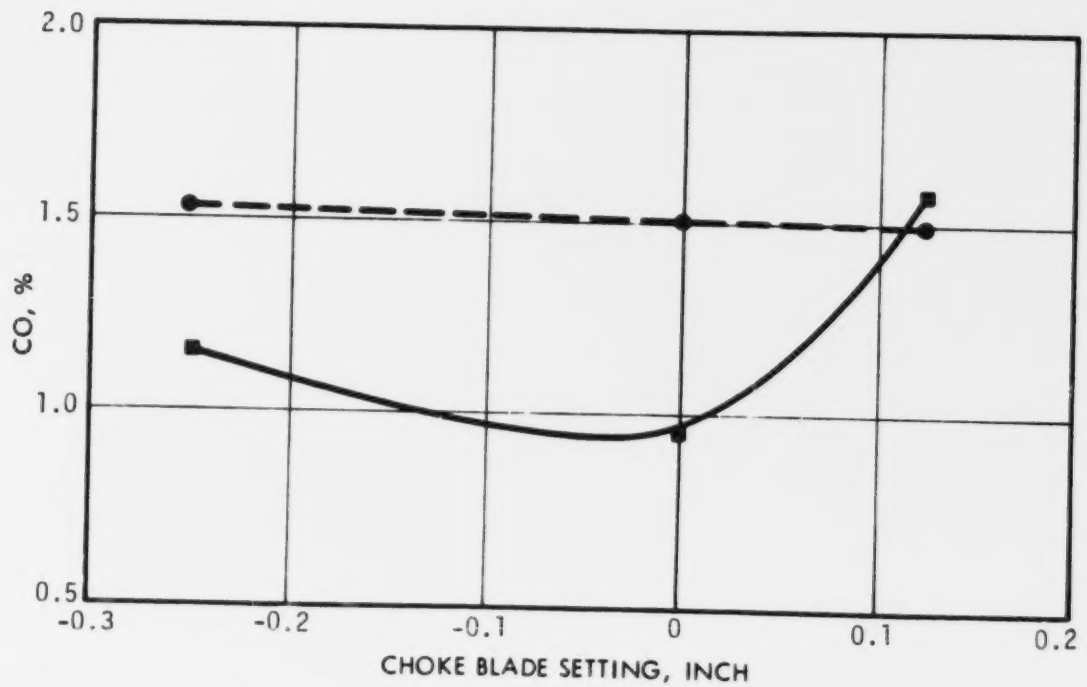


Figure 3-6. CO Emission Response

### 3.2 PARAMETER AND DIAGNOSTIC MODE SELECTION CRITERIA

Parameters to be "maladjusted" during the screening experiment were selected to provide a broad spectrum of engine system parameters. The goal was to identify maladjustments which would produce measurable effects on exhaust emissions. In determining the least number of parameters to accomplish the overall program objectives, the following procedure was used: first, engine parameters were selected which significantly effect exhaust emissions; second, the parameters were grouped according to similar types of effects on emissions. Table 3-17 lists the parameters in 11 groups of similar effects and indicates the approximate ranking of their effects on exhaust emissions.

For the 11 main effects to be incorporated as test parameters, a single maladjustment was identified to simulate a malfunction class which could be adjusted over the normal range of parameter deviation. Rather than concentrating on deviating single components or adjustments, parameters were selected which best represented the gross malfunction characteristics of the subsystem it affected. The adjustment limits were based on parameter survey data, the desire to avoid extreme driveability problems, sufficient emission sensitivity to assure that the effect is greater than the experimental noise and ability to set the deviations in conjunction with similar parameters.

Several diagnostic modes have been recommended for determining malfunctioning components, adjustments, or subsystems known to influence vehicle emissions (References 3,4,5 and 6). All combinations of driving modes (i.e., acceleration, cruise, and decelerations) have been integrated into a cycle driveable on a chassis dynamometer. This driving cycle contains acceleration rates ranging from 2 to 3 mph/sec, cruise ranges from 30 to 60 mph at road load, and cruises at above normal road load conditions (Figure 3-7). The time positions of the actual modes in this driving cycle are also shown.



Table 3-17. Test Parameter Selection

| Parameters Selected                                                                                                                                              | Rough Rank                                        | Parameters Selected                                                                                                                                                                                                                                                 | Rough Rank                                                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 1. <u>Basic Timing</u><br>Distributor Drive (wear)<br>Mechanical Advance<br>Mechanical Retard                                                                    | (3)<br>(19)<br>(17)<br>(17)                       | 7. <u>Air Cleaner Restriction</u>                                                                                                                                                                                                                                   | (9)                                                                          |
| 2. <u>Ignition Primary Circuit</u><br>Point Dwell<br>Point Wear<br>Condenser<br>Primary Resistor<br>Coil Primary<br>Alternator Circuit                           | (2)<br>(5)<br>(2)<br>(25)<br>(26)<br>(21)<br>(27) | 8. <u>Vacuum Advance</u><br>Vacuum Advance Control<br>Vacuum Retard                                                                                                                                                                                                 | (17)<br>(17)<br>(17)                                                         |
| 3. <u>Ignition Secondary Circuit</u><br>Spark Plugs<br>Plug Wires<br>Coil Secondary<br>Distributor Cap & Rotor                                                   | (1)<br>(1)<br>(11)<br>(21)<br>(8)                 | 9. <u>Air Injection System</u><br>Air Pump Pressure<br>Air Pump Hoses<br>Check Valve<br>Gulp Valve                                                                                                                                                                  | (29)<br>(29)<br>(29)<br>(29)<br>(7)                                          |
| 4. <u>Idle Circuit Speed (rpm)</u><br>Throttle Position (decel)                                                                                                  | (4)<br>(4)                                        | 10. <u>Intake Manifold Leaks</u>                                                                                                                                                                                                                                    | (22)                                                                         |
| 5. <u>Idle Circuit Air/Fuel (C0)</u>                                                                                                                             | (7)                                               | 11. <u>PCV Valve</u>                                                                                                                                                                                                                                                | (9)                                                                          |
| 6. <u>Carburetor (Air/Fuel)</u><br>Low Speed (off idle) Circuit<br>High Speed Circuit-Part Load<br>High Speed Circuit-Full Load<br>Enriched Point<br>Float Level | (12)<br>(13)<br>(12)<br>(12)<br>(14)<br>(28)      | 12. <u>Cold Test Parameters</u><br>a. Air Cleaner Thermostat<br>b. Heat Riser<br>c. Choke Relief                                                                                                                                                                    | (14)<br>(6)<br>(10)                                                          |
|                                                                                                                                                                  |                                                   | 13. <u>Parameters Excluded</u><br>a. Accelerator Pump<br>b. Hot Idle Compensator<br>c. Carburetor Bowl Vents<br>d. Fuel System<br>e. Fuel Cutoff<br>f. Engine Deposits<br>g. Piston Rings<br>h. Valves<br>i. Exhaust Back Pressure<br>j. Cooling System Temperature | (29)<br>(29)<br>(30)<br>(18)<br>(31)<br>(27)<br>(16)<br>(13)<br>(23)<br>(22) |

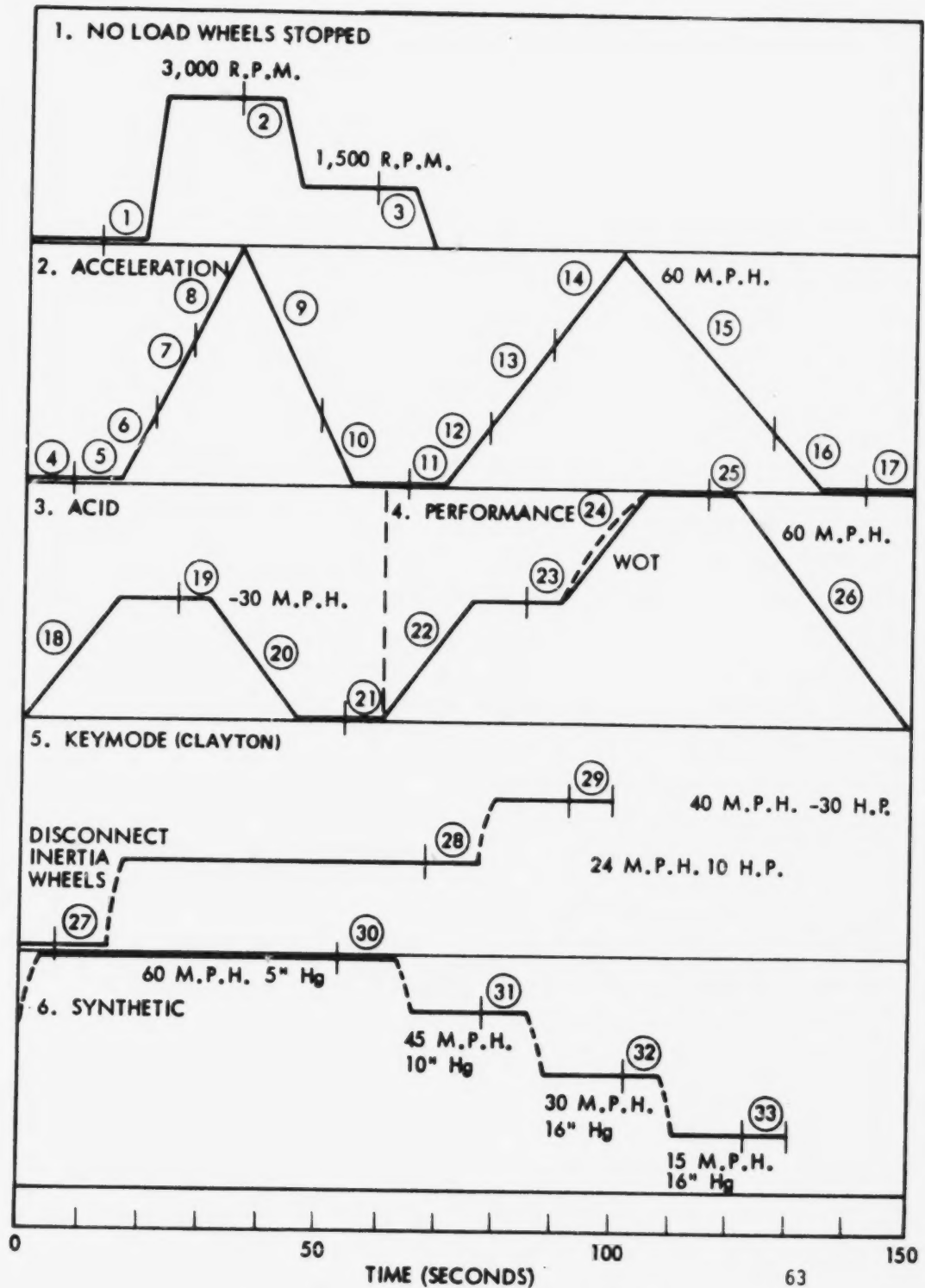


Figure 3-7. Diagnostic Mode. Emissions Screening Experiment

### 3.3 EXPERIMENTAL DESIGN

An experimental program was designed to study the 12 variables (13 for the air injection system, AIR) defined in Table 3-17. Design criteria imposed were that the experiment should:

- Reflect typical power train types within the general population.
- Develop fundamental, generalized data from which optimum engine parameters and emission signatures can be identified.
- Maximize the amount and kind of data per dollar spent.

#### 3.3.1 Power Train Selection

The vehicle power trains selected for testing were required to fit approximately the following population statistical criteria:

- Ratio of 8 to 6 cylinder vehicles
- Ratio of air injection system to engine modification emission control devices
- Percent by manufacturer

A power train matrix complying with these criteria requiring 11 test vehicles was selected (Table 3-7). Five of the eight V-8 engines are middle sized in terms of cubic inch displacement (CID): three are large V-8's in heavier vehicles. The Volkswagen 1300 was selected to reflect the foreign made vehicles within the U.S. population.

#### 3.3.2 Experimental Approach

As emissions tests are expensive to perform, an experimental approach which maximizes data utility per dollar spent is essential to a cost effective program. The analysis of the engine parameter experiment data resulted in the selection of 11 parameters affecting hot cycles and two variables affecting cold cycles. A complete characterization of these variables (main effects and first-order interactions) would require  $2^{13}$  or 8192 tests if the variables are investigated at two levels. This level of testing is obviously not practical. A statistically designed experiment was therefore employed with the following advantages:

- More information acquired per test point
- A measure of experimental error obtained
- Interaction effects investigated economically

Since the first objective is primarily to screen the most attractive engine parameters and emissions diagnostic modes, the experiment was divided into two parts:

- Eleven parameters relatively insensitive to engine temperature
- Two choke parameters sensitive to engine temperature

#### Screening Experiment Orthogonal Tests

A 1/64 replicate of a  $2^{11}$  factorial design was selected for the first experiment. Although this design has low statistical power, it does satisfy the basic requirements for the experiment. The experiment requires 32 emissions tests on each of the 11 "representative" automobiles selected for the program. This design provides for the separate orthogonal estimation of all 11 main effects and up to 15 of the possible 55 two-factor interactions. These interaction estimates, however, are self-confounded in groups of three or four so that to establish one as being significant, it will be necessary to discount the reality of the others in the particular group (Reference 7). Also, a random testing order was followed during the experiment to preclude the possibility of timewise biasing of the desired contrasts. The test matrix is shown in Table 3-18.

For each measured exhaust emission mode, mass and volume weighted, a complete analysis of variance was conducted to estimate each of the 11 main effects and the two-factor interaction terms.

In addition to the variance analysis, a least squares response surface equation of the following form was fitted to each data set:

$$Y_k = B_0 + \sum_{i=1}^n B_i X_i + \sum_{i,j} B_{ij} X_i X_j \text{ (for selected } i,j \text{ pairs)}$$

Table 3-18. Orthogonal Test Matrix - Screening Experiment

| Run No. | Timing DEG/REV | Vacuum Advance | Pt. Res. Avail. Kv = 2.5 Req'd Kv | Ign - Sec. (% Misfire) | Idle CO, (% Dev.) | Idle RPM Deviation | Float Level Deviation | Air Cleaner Restriction AC Tester | PCV Valve Restriction | Air Pump Restriction | Man. Leak CID (1CFM) 302 |
|---------|----------------|----------------|-----------------------------------|------------------------|-------------------|--------------------|-----------------------|-----------------------------------|-----------------------|----------------------|--------------------------|
| 1       | -10            | Norm           | Yes                               | 2.5                    | 2.0 Rich          | -20%               | -1/8" Rich            | 0                                 | 0                     | 100%                 | Yes                      |
| 2       | -10            | Norm           | No                                | 2.5                    | -0.5 Lean         | +10%               | -1/8" Rich            | 0                                 | 100%                  | 0                    | Yes                      |
| 3       | 7              | Norm           | Yes                               | 0                      | -0.5 Lean         | -20%               | -1/8" Rich            | 180°                              | 100%                  | 100%                 | Yes                      |
| 4       | -10            | Norm           | Yes                               | 2.5                    | 2.0 Rich          | -20%               | -1/8" Rich            | 180°                              | 100%                  | 0                    | No                       |
| 5       | 7              | 0              | No                                | 2.5                    | 2.0 Rich          | -20%               | -1/8" Rich            | 180°                              | 100%                  | 0                    | No                       |
| 6       | -10            | Norm           | Yes                               | 0                      | -0.5 Lean         | +10%               | +1/4" Lean            | 180°                              | 100%                  | 0                    | No                       |
| 7       | 7              | Norm           | No                                | 2.5                    | -0.5 Lean         | -20%               | +1/4" Lean            | 0                                 | 100%                  | 100%                 | No                       |
| 8       | -10            | 0              | Yes                               | 0                      | 2.0 Rich          | +10%               | -1/8" Rich            | 0                                 | 100%                  | 100%                 | No                       |
| 9       | 7              | Norm           | No                                | 2.5                    | -0.5 Lean         | -20%               | +1/4" Lean            | 180°                              | 0                     | 0                    | Yes                      |
| 10      | 7              | Norm           | Yes                               | 2.5                    | 2.0 Rich          | +10%               | +1/4" Lean            | 0                                 | 0                     | 0                    | No                       |
| 11      | 7              | 0              | No                                | 0                      | -0.5 Lean         | +10%               | +1/4" Lean            | 0                                 | 0                     | 100%                 | Yes                      |
| 12      | -10            | Norm           | Yes                               | 0                      | -0.5 Lean         | +10%               | +1/4" Lean            | 0                                 | 0                     | 100%                 | Yes                      |
| 13      | 7              | 0              | Yes                               | 0                      | 2.0 Rich          | -20%               | +1/4" Lean            | 0                                 | 100%                  | 0                    | Yes                      |
| 14      | 7              | Norm           | Yes                               | 2.5                    | 2.0 Rich          | +10%               | +1/4" Lean            | 180°                              | 100%                  | 100%                 | Yes                      |
| 15      | 7              | 0              | No                                | 0                      | -0.5 Lean         | +10%               | +1/4" Lean            | 180°                              | 100%                  | 0                    | No                       |
| 16      | -10            | 0              | No                                | 2.5                    | 2.0 Rich          | +10%               | +1/4" Lean            | 180°                              | 100%                  | 100%                 | Yes                      |
| 17      | 7              | 0              | No                                | 2.5                    | 2.0 Rich          | -20%               | -1/8" Rich            | 0                                 | 0                     | 100%                 | Yes                      |
| 18      | -10            | 0              | No                                | 0                      | -0.5 Lean         | -20%               | -1/8" Rich            | 180°                              | 100%                  | 100%                 | Yes                      |
| 19      | 7              | Norm           | No                                | 0                      | 2.0 Rich          | +10%               | -1/8" Rich            | 180°                              | 0                     | 0                    | Yes                      |
| 20      | 7              | Norm           | No                                | 0                      | 2.0 Rich          | +10%               | -1/8" Rich            | 0                                 | 100%                  | 100%                 | No                       |
| 21      | 7              | 0              | Yes                               | 2.5                    | -0.5 Lean         | +10%               | -1/8" Rich            | 0                                 | 100%                  | 0                    | Yes                      |
| 22      | -10            | 0              | No                                | 0                      | -0.5 Lean         | -20%               | -1/8" Rich            | 0                                 | 0                     | 0                    | Yes                      |
| 23      | -10            | 0              | Yes                               | 2.5                    | -0.5 Lean         | -20%               | -1/8" Rich            | 180°                              | 0                     | 0                    | No                       |
| 24      | -10            | 0              | Yes                               | 0                      | 2.0 Rich          | +10%               | -1/8" Rich            | 180°                              | 0                     | 0                    | Yes                      |
| 25      | -10            | Norm           | No                                | 2.5                    | -0.5 Lean         | +10%               | -1/8" Rich            | 180°                              | 0                     | 100%                 | No                       |
| 26      | 7              | 0              | Yes                               | 0                      | 2.0 Rich          | -20%               | +1/4" Lean            | 180°                              | 0                     | 100%                 | No                       |
| 27      | -10            | 0              | Yes                               | 2.5                    | -0.5 Lean         | -20%               | +1/4" Lean            | 0                                 | 100%                  | 100%                 | No                       |
| 28      | 7              | Norm           | Yes                               | 0                      | -0.5 Lean         | -20%               | -1/8" Rich            | 0                                 | 0                     | 0                    | No                       |
| 29      | -10            | 0              | No                                | 2.5                    | 2.0 Rich          | +10%               | +1/4" Lean            | 0                                 | 0                     | 0                    | No                       |
| 30      | -10            | Norm           | No                                | 0                      | 2.0 Rich          | -20%               | +1/4" Lean            | 180°                              | 0                     | 100%                 | No                       |
| 31      | -10            | Norm           | No                                | 0                      | -0.5 Lean         | -20%               | +1/4" Lean            | 0                                 | 100%                  | 0                    | Yes                      |
| 32      | 7              | 0              | Yes                               | 2.5                    | -0.5 Lean         | +10%               | -1/8" Rich            | 180°                              | 0                     | 100%                 | No                       |

where:

$B_i$  = slope coefficient

$Y_k$  = mode or weighted emission measurement

$X_i$  = parameter adjustment, deviation from specification

From this equation, it is possible to generate an emission level response surface for each emission specie and to assess the relative significance of each of the independent variables,  $X_i$ .

To minimize test costs, these emissions tests were performed for the hot cycles of the Federal procedure. An identical engine warm-up procedure was followed for every test to control the initial temperature of the engine block. This key temperature was shown in the Vehicle Emissions Surveillance Study to significantly affect emissions.

Hot cycle testing also improves the precision of the test since the more variable carburetor choke effects are not present. Detailed test procedures and emissions response surfaces are discussed in the following subsection.

#### Choke Tests

The 11 engine parameters selected for study in the orthogonally designed experiment are not substantially influenced by power train temperature. A subexperiment on the 11 vehicles was performed to investigate the carburetor choke subsystem. This experiment evaluated the effect of choke linkage maladjustments on vehicle emissions as measured by the full, cold start procedure (i.e., starting with a power train at ambient conditions). Both heat riser valve and the choke relief (blade angle setting) were evaluated at two and three levels of their parameter setting, respectively. This was done using a full factorial design requiring six emissions tests. All other adjustments and failure simulations were returned to manufacturers' recommended states except for the choke adjustments.



### Base Emissions

To establish limits on the maximum emissions decrements to be affected through maintenance, the 11 vehicles selected for the statistically designed experiment underwent two additional tests. These were a complete diagnosis of the general engine maintenance state and a Federal emissions test for both the vehicle as received and after a major engine tuneup. The maintenance effectiveness in reducing emissions is simply the difference in the two emissions measurements.

## 3.4 TEST PROCEDURE

### 3.4.1 Vehicle Preparation

Before a test vehicle was run on the parameter screening experiment, it received an oil and filter change, then was tested for exhaust emissions from a cold start and with the diagnostic modes. The vehicle was then given a thorough diagnostic inspection (based on the parameter survey procedure), a major tuneup, and repaired as indicated by the diagnostic inspection. The cold start and diagnostic mode exhaust emission tests were then repeated. This procedure provided information on the initial and post tuneup state of the vehicle as to both exhaust emissions and engine parameters. Also, the data were used to expand the parameter survey and evaluate the effectiveness of the inspection procedure.

Inspection for the parameter screening experiment was more detailed than the parameter survey with respect to carburetor diagnosis. This was because % CO readings were available from the diagnostic modes before the tuneup. In addition, time requirements for inspecting only 11 vehicles are less demanding. Also, inspection of carburetor adjustments was more comprehensive. Percent CO readings were taken from strip charts for various diagnostic modes to detect serious discrepancies in the carburetor metering circuits.

Engine tuneups were performed to ensure a good base line for the main experiment and to prevent undetected or incipient malfunctions from influencing test results. The tuneup procedure was based entirely on recommended shop procedures and specifications; there were no deviations

from this criterion. By following this procedure, the test results were more indicative of the exhaust emission reduction which could result from field repairs and maintenance. Only malfunctions which could be detected during inspection and corrected by engine tune-up and normal maintenance were determined. No vehicles were rejected from the experiment for mechanical problems.

To establish a good experimental base line, tuneups always included new spark plugs, ignition points and condenser, PCV valve, air cleaner element, fuel filter, and carburetor kit. Additional parts were replaced when indicated by the diagnostic inspection. Typical parts replaced were ignition wires, distributor cap, and rotor. Occasionally there were insufficient data available for carburetor adjustment, particularly for idle setting procedures. Also, the technique to be used for carburetor mechanical adjustment was not always clear. In examining several shop data sources, we often found disagreement both on procedures and specifications. Whenever possible, the manufacturer's shop manual was used as the primary source of information. Idle mixture setting data were particularly limited and usually stated in terms of air-fuel ratio (as measured with a thermal conductivity instrument), best lean idle, or a prescribed rpm drop caused by mixture screw settings. The idle %CO resulting from the idle setting procedure was used as the null point for the idle %CO settings in the parameter screening experiment. As in the other tuneup specifications, the idle %CO was set using only the available shop data. No attempt was made to use sophisticated methods for balancing the carburetor side-to side or to obtain an optimum air-fuel mixture for minimum hydrocarbon emissions.

This type of procedure was used to best represent the type of work to be done in the field by competent mechanics.

#### 3.4.2 Measurements and Special Test Equipment

Exhaust emission analyses were performed with basic nondispersive infrared equipment as specified in the Federal Register, June 4, 1968, as well as with equipment for analysis of oxides of nitrogen and composite dilute bag samples. The equipment was constructed so that bag

samples could be taken concurrently with direct concentration readings. Mass emissions were obtained from the mass sampler system, which is effectively a temperature controlled constant volume through-flow device. Bag samples were collected of proportional dilute gas compositions in either a "hot bag" or a "cold bag," and a "background bag," as shown in Figure 3-8, and were analyzed as described below. The combined system was constructed for operator efficiency, and was capable of both complete and semiautomatic operation. Additional details of the mass emission management technique are described in the Federal Register.

Figure 3-8 shows a schematic of the entire emission instrumentation system. Several special considerations ensured data reliability. All direct concentration samples analyzed for HC, CO, CO<sub>2</sub>, NO, and NO<sub>2</sub> were returned to the total exhaust duct without transit delays through the duct and analysis system. Because of the return of direct concentrated samples from the analysis system, uniform pressures in the sample cells had to be assured. This was accomplished by maintaining regulated flow through all instruments during all operational modes. If either sample or calibration gas were not flowing through an instrument, nitrogen was employed to maintain the correct total flow and sample cell pressure.

Direct concentration readings were made of HC, CO, CO<sub>2</sub>, and NO using NDIR instrumentation. NO<sub>2</sub> concentrations were analyzed using nondispersive ultraviolet detection. Bag sample analyses were accomplished by flame ionization detection for total hydrocarbon, low range CO (0-10%), low range NO (0-500 ppm), and normal range NO<sub>2</sub> (0-200 ppm). The cold bag was collected during 7-mode cycles one through four, and the hot bag was filled during cycles five through nine. The background bag was filled over all nine cycles to sample the actual dilution air for the constant volume system.

To produce controlled ignition misfire and point resistance, it was necessary to design a misfire generator. The point signal was periodically shorted to induce misfire, and a variable resistance was put in series with the primary ignition circuit. The misfire generator was constructed to provide several percentages of misfire from 5 to 2%. A 2.5% rate was finally selected and the misfire simulator set to

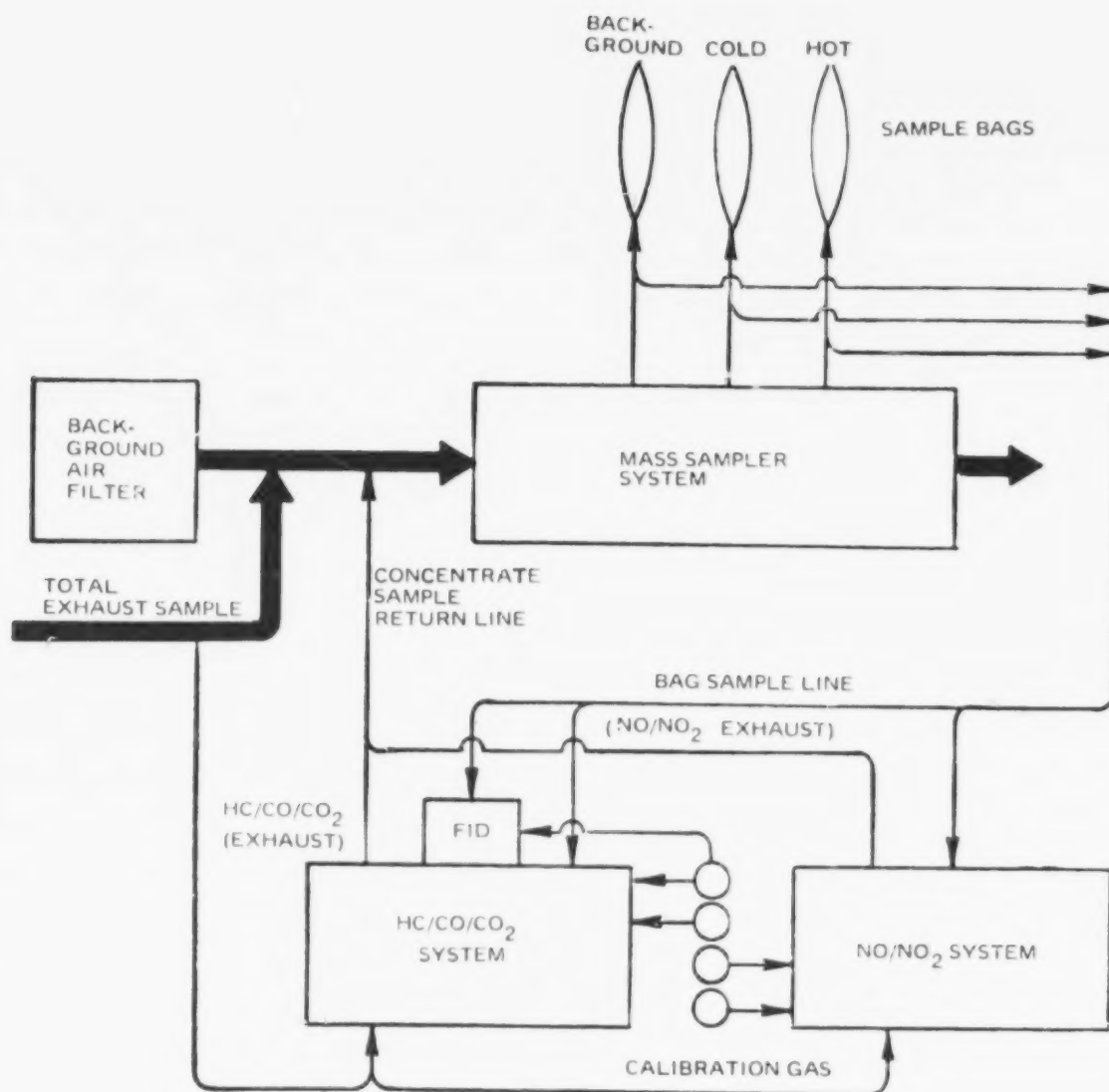


Figure 3-8. Flow Schematic for Simultaneous Composite and Mass Sampling

produce one misfire in every 39 firings (2.56%). The odd number of firings was used to ensure that misfirings would be equally distributed among all spark plugs in the engine and no one cylinder would be unduly deteriorated. Figure 3-9 shows a schematic of the misfire generator and vehicle installation circuits. Development problems with the misfire simulator were caused by radio frequency interference, both internal (caused by misfires themselves) and external (caused by normal spark ignition). Improved radio interference shielding and grounding were required to eliminate these problems. The misfire generator operated properly under all engine speeds and loads encountered during the test series and without affecting ignition timing.

#### 3.4.3 Orthogonal Test Procedures

The main, or orthogonal, experiment of this program consisted of systematically detuning (adjusting to an out-of-specification condition) the 11 representative engine parameters/settings as specified in the test matrix. Nine Federal emission cycles (7-mode) were run from a hot start and the exhaust emissions continuously monitored and bag samples measured as described in section 3.4.2. Immediately after the 7-mode cycles and bag analyses, six short, or diagnostic, cycles were run and direct concentration exhaust emissions measured. The engine was then set to the next detune state and the emission tests repeated until all 32 orthogonal tests had been completed on that vehicle.

The following sequence and adjustment procedures were used to set the mistuned parameters for each orthogonal test:

1. The carburetor float level was set either 1/8 inch high (rich) or 1/4 inch low (lean).
2. On vehicles with engine modification emission control, the hose from the PCV valve was either normally open or completely blocked off. On vehicles equipped with air injection systems, the PCV valve system was not adjusted, but the air pump was allowed to operate normally or the air distribution hoses were disconnected and the distribution manifolds sealed.
3. A calibrated orifice was installed in a centrally located vacuum accessory hose when manifold leakage was called for, and the normal installation was used for the standard condition. Figure 3-10 illustrates a typical installation.

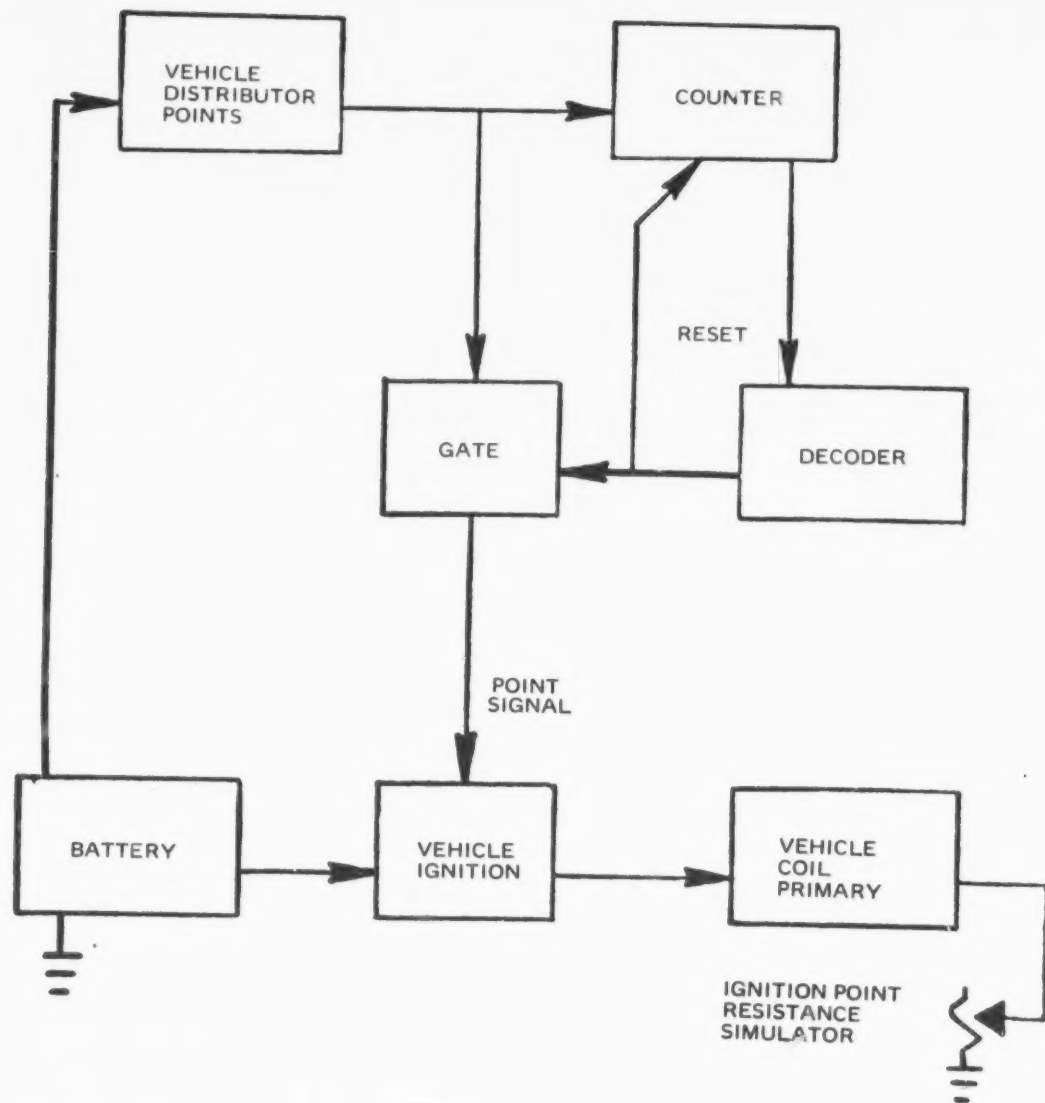


Figure 3-9. Ignition Misfire Generator



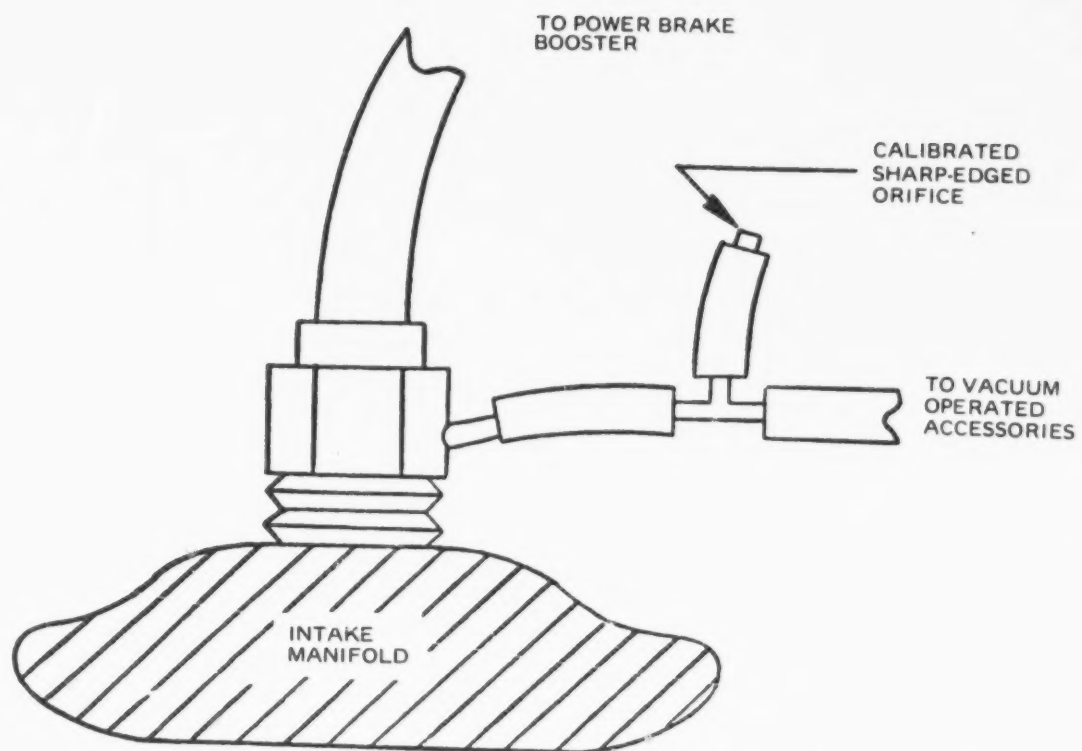


Figure 3-10. Vacuum Leak Rate Simulator

4. Either a new air filter element or an element taped partially closed (with five equal area, vertical openings) produced the desired restriction.
5. The ignition misfire generator was turned either off or on as specified.
6. The ignition point resistance switch was turned off or on as specified.
7. The distributor vacuum advance hose was either connected or disconnected as specified. If it was disconnected, the hose was plugged to prevent leaks.
8. The ignition timing was set to the desired deviation from manufacturer's specification. The vacuum advance hose was temporarily disconnected if it was to be connected for this test.
9. The idle rpm was set to the desired deviation from manufacturer's specification.
10. The idle %CO was set to the desired deviation from the reference %CO determined after engine tuneup. The idle rpm was maintained during the setting, and the procedure described in Section 3.4.5 was used to maintain engine temperature consistency.

One of the 11 vehicles in the experiment was a 1968 Volkswagen which required some test design modifications before successfully undergoing the experiment. It was found that under mistuned conditions, the vehicle's speed and acceleration capabilities were inadequate for both 7-mode and short-cycle tests. Thus the vehicle speed was consistently reduced to 45 mph for the 7-mode tests from the normally specified 50 mph. For the short cycles the following changes were made:

1. 0-60 mph quick acceleration - changed to 0-33 mph.
2. 0-60 mph acceleration - changed to 0-45 mph.
3. ACID cycle 30 cruise - third gear instead of fourth gear.
4. Performance Cycle 30 cruise - third gear instead of fourth, 30-60 mph wide open throttle acceleration was 30-40 mph, and 60 mph cruise was reduced to 45 mph cruise.
5. Keymode Cycle loading was changed from 10 road horse power at 24 mph to 2 hp. The fourth gear 40 mph cruise at 30 road horse power was changed to third gear 40 mph at 5 road horse power.

6. For the Synthetic Cycle the 60 mph cruise was eliminated and the engine manifold vacuum settings at 45, 30 and 15 mph were changed to 9, 14 and 16 inches Hg, respectively, in second gear.

Certain other modifications to the Volkswagen were also required with respect to the parameter maladjustments. The vacuum advance maladjustment was eliminated from the test because the vehicle had only a vacuum controlled spark advance. The PCV system consisted of a single crankcase-to-air cleaner hose and when a test called for a plugged PCV system, the hose was removed and the air cleaner fitting plugged. The air cleaner was of the oil bath type so the air cleaner restriction parameter was deleted from the experiment. The spark timing adjustment for retard was reduced from 10 to 5 degrees. The float level was not adjustable at the float and was changed by varying the thickness of the shim gasket under the needle seat until the effective float setting was 0.043 inch rich and 0.179 inch lean.

#### 3.4.4 Cold Engine Parameter Tests

A subexperiment, run concurrently with the orthogonal experiment, involved maladjusting engine parameters that influenced cold engine exhaust emissions. While running each vehicle on the test schedule and at the end of each work shift, engine parameters were returned to normal specifications and the choke relief (vacuum kick, vacuum break, pull-down) and heat riser valve, or air cleaner hot air inlet door control, varied according to test requirements. The vehicle was allowed to soak overnight and a cold start test was run the next day with the same procedures used for the main experiment, including short cycles. Table 3-19 shows the six combinations of choke pull-down and heat riser settings tested. Only one vehicle (Car 505, 1966 Ford Mustang with 200-cubic inch displacement six cylinder engine) had neither heat riser valve nor hot air inlet door.

#### 3.4.5 Test and Measurement Quality Control

Efforts were made to ensure that the condition of every vehicle was as consistent as possible for each test. The idle rpm and % CO were always measured and set with a warm engine. During the actual idle setting, the engine was never idled for prolonged periods of time, and a 0 to 50 to 0

Table 3-19. Choke Relief and Heat Riser Test Schedule

| Test No. | Choke Relief Deviation | Heat Riser Setting |
|----------|------------------------|--------------------|
| A        | 0                      | Operating          |
| B        | +1/16" (Rich)          | Operating          |
| C        | -1/8" (Lean)           | Operating          |
| D        | 0                      | Stuck Open*        |
| E        | +1/16" (Rich)          | Stuck Open*        |
| F        | -1/8" (Lean)           | Stuck Open*        |

\* On cars equipped with air inlet temperature control, secure air mixing door to receive underhood air only (no exhaust heat).

clean out was made intermittently with the desired idle and %CO being confirmed immediately after clean out. The instrument system was then spanned and set at zero with nitrogen. Two mid-point calibration gases were recorded as a curve check for the CO, CO<sub>2</sub>, and HC instruments.

The composite bag samples were analyzed immediately after completion of the 7-mode cycles and the low-range instrument calibration. Any undue delay in taking these readings was considered unacceptable (because of excessive thermal conversion of NO and HC in the sample bags) and the run repeated. After each test all sample bags were purged with nitrogen to eliminate residuals. The nitrogen purge gas was left in the bags overnight as an extra precaution.

To assure compliance with the orthogonal test design, an Engine Parameter Deviation Check List was used to provide the mechanic with the desired adjustment for each experiment run. Before a vehicle was started on the main experiment, the "desired" settings were listed for each run by the project engineer. These settings were based on the manufacturer's specification and the designed experimental deviation. The test driver filled in the columns labeled "Achieved" as the mechanic made the setting. This provided a permanent record of that parameter setting and served as a check that the setting was actually made or could not be made.

### 3.5 DATA REDUCTION AND ANALYSIS PROCEDURE

Data for all of the above tests were manually reduced. Templates were fabricated to facilitate the manual reading of the emissions strip chart time traces. The Federal and diagnostic mode emissions and the pre- and post-instrument calibration check data were read and the data were converted to punched cards. Mode-emissions averaging was accomplished by approximately balancing areas on both sides of the mode emission mean level. The 1966 Federal data reduction procedures were used (i.e., the dilution factor was calculated from the expression,  $15/(6 \text{ HC} + \text{CO} + \text{CO}_2)$ ).

A computerized data reduction program was written to convert these data to concentration measurements, both mode, cycle, and composite.

The instrument calibration curve was fitted with the law of optics governing its operation, Reference 8. Typical computer program data output for the full Federal emissions test and the diagnostic modes are shown in Table 3-20.

An optional subroutine to the above described data reduction program was written to perform the statistical calculations pertinent to the interpretation of the data. The following data were calculated:

- Emissions response surfaces for mass, composite and mode emissions
- Analysis of variances for emission response statistical significance
- Analysis of variances for postulated engine parameter interactions



Table 3-20. Reduced Test Data Printout

6C1 U7N156 565 8 CHEVROLET WAGON 1967 54171 327 RUCH 4 3 1 2

HOT COEFFICIENTS (CYCLES 6 - 7)

|     | K0            | K1             | DATE     |
|-----|---------------|----------------|----------|
| CO  | 8.0000000E-03 | 1.28450000E-01 | 12-04-69 |
| CO2 | 7.9000000E-03 | 9.68060000E-02 | 12-29-59 |
| LHC | 3.2000000E-03 | 2.56370000E-04 | 11-07-69 |
| HHC | 4.6000000E-03 | 6.15940000E-05 | 11-07-59 |
| NOX | 6.6000000E-03 | 2.85400000E-04 | 11-07-59 |

+++ ENGINEERING UNITS +++

|         | ZERO | IDLE  | 0-25  | 30CR  | 30-15 | 15CR | 15-30 | 50-20  |
|---------|------|-------|-------|-------|-------|------|-------|--------|
| CYCLE 6 | CO   | 6.4   | 2.0   | 1.9   | 1.8   | 1.4  | 1.7   | 1.0    |
| CYCLE 6 | CO2  | 7.7   | 9.9   | 8.8   | 10.8  | 11.0 | 9.6   | 8.6    |
| CYCLE 6 | LHC  | 353.8 | 210.3 | 153.1 | 265.4 | 79.4 | 193.2 | 76.5   |
| CYCLE 6 | HHC  | 0.0   | 0.0   | 0.0   | 0.0   | 0.0  | 0.0   | 1529.3 |
| CYCLE 6 | NOX  | 20.9  | 744.4 | 329.3 | 58.4  | 48.9 | 890.4 | 193.5  |
| CYCLE 7 | CO   | 6.3   | 2.4   | 1.9   | 1.9   | 1.3  | 1.9   | 1.0    |
| CYCLE 7 | CO2  | 7.9   | 9.6   | 8.8   | 11.1  | 11.4 | 9.5   | 8.8    |
| CYCLE 7 | LHC  | 363.4 | 239.4 | 177.5 | 255.8 | 85.8 | 255.0 | 71.6   |
| CYCLE 7 | HHC  | 0.0   | 0.0   | 0.0   | 0.0   | 0.0  | 0.0   | 1428.0 |
| CYCLE 7 | NOX  | 23.2  | 807.9 | 316.8 | 60.8  | 34.9 | 744.4 | 173.5  |

Table 3-20. Reduced Test Data Printout (Cont.)

FEDERAL CYCLE RESULTS

|     | COMPOSITES |     |        |       |
|-----|------------|-----|--------|-------|
|     | VOLUME     | HOT | MASS   | COLD  |
| HC  | 327.281    |     | 4.153  | 0.000 |
| CO  | 2.732      |     | 65.092 | 0.000 |
| NOX | 821.488    |     | 2.098  | 0.000 |

MEANS PER MODE  
HOT CYCLE ONLY

|     | 1       | 2       | 3       | 4       | 5      | 6       | 7        |
|-----|---------|---------|---------|---------|--------|---------|----------|
| CO  | 6.363   | 2.234   | 1.906   | 1.819   | 1.339  | 1.777   | .978     |
| CO2 | 7.784   | 9.777   | 8.813   | 10.957  | 11.195 | 9.558   | 8.692    |
| HC  | 358.625 | 224.816 | 170.305 | 260.532 | 82.627 | 199.094 | 1542.709 |
| NOX | 22.039  | 776.142 | 313.054 | 59.589  | 41.882 | 817.395 | 183.482  |

#### 4. DEFINITIVE EXPERIMENT

The results of the screening experiment clearly pointed to seven engine parameters as having the most leverage in a mandatory maintenance program. This determination was based on the frequency and extent of the malfunction as well as the emission sensitivity to malfunction. Some of these malfunctions are known to have nonlinear effects over the range of variables evaluated.

The design of the definitive experiment was directed at three areas:

- Number of levels of the variables to be studied to characterize nonlinearities
- Test controls for minimizing residual error
- Statistical power of the experiment to characterize parameter interactions

The results of the experimental program are given below.

##### 4.1 TEST RESULTS AND CONCLUSIONS

Summary tables of the results of the definitive, statistically designed parameter experiments are presented in Tables 4-1 through 4-3 for composite and mass HC, CO, and NO emissions, respectively. These data were abstracted from more complete data sheets in Appendix B. Data summarized are the emissions responses,  $de/dp$ , for the individual parameters evaluated on 11 power trains. Power train attributes (make, model, etc.) can be found on Table 4-14 by keying through vehicle number.

Emission response sign conventions are based on emission change in going from low to the high value of an adjustment or from the failed to the nominal state of a malfunction. For example, if the emission change in going from timing retard (-1) to advance (+1) is positive, the emission value increases, and vice versa.

##### 4.1.1 HC Emissions Response

The HC composite emission response to timing maladjustment (Table 4-1a) is seen to be fairly consistent across power trains. Vehicles (605, 607 and 608)

TABLE 4-1a  
HC COMPOSITE EMISSIONS RESPONSE SURFACE COEFFICIENTS

Emission Response to Engine Parameters

| Car No. | Timing  | Definitive Experiment                                    |                         |             |               |          |
|---------|---------|----------------------------------------------------------|-------------------------|-------------|---------------|----------|
|         |         | Engine Parameter Response, $\partial c_i / \partial p_i$ |                         |             |               |          |
|         |         | Idle RPM                                                 | PCV                     | Air Cleaner | Idle CO       | Air Pump |
|         | ppm/deg | ppm/rpm                                                  | ppm/in.H <sub>2</sub> O | ppm/deg     | ppm/%         |          |
| 601     | 10.65*  | -0.527*                                                  | -                       | 0.05        | 18.6/.44      | -155.0*  |
| 602     | 10.3*   | -0.383*                                                  | -                       | 0.12*       | -1.9/13.5     | -112.2*  |
| 603     | 8.6*    | -0.712*                                                  | 50.4*                   | 0.078       | -0.4/26.5*    | -        |
| 604     | 9.91*   | -0.354*                                                  | 49.3                    | 0.516*      | -52.4/16.0    | -        |
| 605     | 2.9     | -0.672*                                                  | -119.8                  | -0.185      | -132.3/-45.3* | -        |
| 606     | 11.9*   | -1.007*                                                  | 71.6*                   | 0.147       | -44.4/-5.4*   | -        |
| 607     | 4.9*    | -0.965*                                                  | -66.2                   | 0.211       | -26.9/-29.07  | -        |
| 608     | 5.5*    | -0.128*                                                  | 74.9*                   | 0.068       | 10.2/7.4      | -        |
| 609     | 10.2*   | -0.589*                                                  | 84.0                    | -0.188      | 39.9/-33.7    | -        |
| 610     | 7.1*    | -0.695*                                                  | -                       | -0.303      | 59.9/-50.1    | 216.9*   |
| 611     | 8.1*    | -0.665*                                                  | 138.0*                  | 0.406*      | 5.2/2.07      | -        |

\*Statistically significant at the 90 per cent confidence level.

TABLE 4-1b  
HC MASS EMISSIONS RESPONSE SURFACE COEFFICIENTS  
Emission Response to Engine Parameters

Definitive Experiment  
Engine Parameter Response,  $\partial e_i / \partial p_i$

| Car No. | Timing<br>g/m/deg | Idle RPM<br>g/m/rpm | PCV<br>g/m/in.H <sub>2</sub> O | Air Cleaner<br>g/m/deg | Idle CO<br>g/m/% | Air Pump |
|---------|-------------------|---------------------|--------------------------------|------------------------|------------------|----------|
| 601     | 0.062*            | -0.0077*            | -                              | 0.00175                | 0.85/-0.13*      | 3.14*    |
| 602     | 0.089*            | -0.0054*            | -                              | 0.00218                | -0.13/0.19       | 1.02*    |
| 603     | 0.046*            | -0.0087*            | 1.02                           | -0.00069               | -0.02/0.25       | -        |
| 604     | 0.12*             | -0.0067*            | 1.09*                          | 0.0083*                | -0.68/0.33*      | -        |
| 605     | 0.016             | -0.009              | -1.67                          | -0.00177               | -1.76/-0.49      | -        |
| 606     | 0.052*            | -0.011*             | 1.56                           | 0.00266                | -0.71/0.62       | -        |
| 607     | -0.0082           | -0.0038*            | 0.07                           | -0.00177*              | -0.046/0.123     | -        |
| 608     | 0.027             | -0.0021             | 1.42*                          | 0.00012                | 0.20/0.087       | -        |
| 609     | 0.072*            | -0.0042*            | 0.27                           | -0.00127               | 0.31/-0.20       | -        |
| 610     | 0.039*            | -0.0058*            | -                              | 0.00091                | -0.07/0.167      | 3.25*    |
| 611     | 0.028*            | -0.0028*            | 0.36                           | 0.00305*               | 0.04/-0.02       | -        |

\*Statistically significant at the 90 per cent confidence level.

TABLE 4-2a  
CO COMPOSITE EMISSIONS RESPONSE SURFACE COEFFICIENTS  
Emission Response to Engine Parameters

| Car No. | Timing<br>%/deg | Definitive Experiment<br>Engine Parameter Response, $\partial e_i / \partial p_i$ |                       |             |                   |          |
|---------|-----------------|-----------------------------------------------------------------------------------|-----------------------|-------------|-------------------|----------|
|         |                 | Idle RPM                                                                          | PCV                   | Air Cleaner | Idle CO           | Air Pump |
|         |                 | %/rpm                                                                             | %/in.H <sub>2</sub> O | %/deg       | %CO/%             |          |
| 601     | 0.0187*         | 0.00001                                                                           | -                     | 0.00163     | 0.15/0.30*        | 1.765*   |
| 602     | 0.0025          | -0.0031*                                                                          | -                     | 0.0049*     | -0.064/<br>0.254* | 1.267*   |
| 603     | -0.0004         | 0.0015*                                                                           | 0.727*                | 0.000615*   | 0.287/0.19*       | -        |
| 604     | 0.0076          | 0.001                                                                             | 2.507*                | 0.0103*     | -0.89/0.405       | -        |
| 605     | -0.020*         | 0.0018*                                                                           | 0.151                 | 0.00107     | 0.396/0.211*      | -        |
| 606     | 0.0043          | 0.00074*                                                                          | 0.938*                | 0.00006     | 0.215/0.141*      | -        |
| 607     | -0.0100*        | 0.00053                                                                           | -0.267                | -0.00262*   | 0.179/0.082*      | -        |
| 608     | +0.007*         | 0.00048                                                                           | 1.551*                | 0.00208*    | 0.415/0.295*      | -        |
| 609     | -0.0202*        | 0.00095*                                                                          | 0.709*                | -0.00059*   | 0.088/0.197*      | -        |
| 610     | -0.012*         | 0.00055                                                                           | -                     | 0.00132*    | -0.153/.335*      | 1.325*   |
| 611     | 0.0004          | 0.0035*                                                                           | 0.989                 | 0.016*      | 0.321/0.248       | -        |

\*Statistically significant at the 90 per cent confidence level.



TABLE 4-2b  
CO MASS EMISSIONS RESPONSE SURFACE COEFFICIENTS  
Emission Response to Engine Parameters

Definitive Experiment  
Engine Parameter Response,  $\partial e_i / \partial p_i$

| Car No. | Timing<br>g/m/deg | Idle RPM<br>g/m/rpm | PCV<br>g/m/in.H <sub>2</sub> O | Air Cleaner<br>g/m/deg | Idle CO<br>g/m/% | Air Pump |
|---------|-------------------|---------------------|--------------------------------|------------------------|------------------|----------|
| 601     | -0.579*           | 0.0018              | -                              | 0.013                  | 3.46/-5.26       | 22.64*   |
| 602     | -0.235            | 0.0086              | -                              | 0.112*                 | 1.5/5.67*        | 22.84*   |
| 603     | -0.241*           | 0.052*              | 2.29                           | 0.0085                 | 6.23/4.73*       | -        |
| 604     | -1.18             | 0.030               | 61.24*                         | 0.242*                 | 0.176/16.14      | -        |
| 605     | -0.71*            | 0.042*              | 1.22                           | 0.0332*                | 8.06/4.21*       | -        |
| 606     | -0.294*           | 0.058*              | 16.24*                         | -0.0095                | 9.11/6.84*       | -        |
| 607     | -0.31*            | 0.028*              | -3.73                          | 0.0536*                | 4.60/2.55*       | -        |
| 608     | -0.091            | 0.031*              | 27.04*                         | 0.0522*                | 14.94/10.4*      | -        |
| 609     | -1.39*            | 0.00088             | 16.89                          | -0.0069                | 17.06/.187       | -        |
| 610     | -0.841*           | 0.040*              | -                              | 0.0451*                | -9.78/12.14*     | 39.39*   |
| 611     | 0.0018            | 0.067*              | 9.31                           | 0.2026*                | 5.56/3.05*       | -        |

\*Statistically significant at the 90 per cent confidence level.

TABLE 4-3a  
NO COMPOSIT EMISSIONS RESPONSE SURFACE COEFFICIENTS  
Emission Response to Engine Parameters

| Car<br>No. | Timing<br>ppm/deg | Definitive Experiment<br>Engine Parameter Response, $\partial e_i / \partial p_i$ |                         |             |             |          |
|------------|-------------------|-----------------------------------------------------------------------------------|-------------------------|-------------|-------------|----------|
|            |                   | Idle RPM                                                                          | PCV                     | Air Cleaner | Idle CO     | Air Pump |
|            |                   | ppm/rpm                                                                           | ppm/in.H <sub>2</sub> O | ppm/deg     | ppm/%       |          |
| 601        | 30.7*             | 0.122                                                                             | -                       | -0.425      | -14/-86.7*  | - 29     |
| 602        | 29.8*             | 0.358*                                                                            | -                       | -1.248*     | 66/-50.5    | - 181*   |
| 603        | 53.6*             | -0.510*                                                                           | -456*                   | 0.538*      | -130/51.1*  | -        |
| 604        | 20.1*             | 0.220                                                                             | -318*                   | -1.627*     | 13/-53.3    | -        |
| 605        | 33.1*             | -0.426*                                                                           | 104                     | 0.256       | -51/44.3    | -        |
| 606        | 63.9*             | -0.525                                                                            | -1602*                  | 0.133       | -220/225    | -        |
| 607        | 39.3*             | 0.331                                                                             | 222*                    | -0.717*     | -142/64.3   | -        |
| 608        | 35.2*             | -0.07                                                                             | -711*                   | -0.236      | -1.9/-87.5* | -        |
| 609        | 34.8*             | -0.141                                                                            | -240*                   | 0.439       | 37/-11.3    | -        |
| 610        | 31.0*             | 0.04                                                                              | -                       | -1.640*     | 189/-105.7  | 70.4     |
| 611        | 27.1*             | -0.963                                                                            | -356                    | -1.044*     | -239/49.5   | -        |

\*Statistically significant at the 90 per cent confidence level.

TABLE 4-3b  
NO MASS EMISSIONS RESPONSE SURFACE COEFFICIENTS

| Emission Response to Engine Parameters |                                                          |                     |                                |                        |                  |          |
|----------------------------------------|----------------------------------------------------------|---------------------|--------------------------------|------------------------|------------------|----------|
| Definitive Experiment                  |                                                          |                     |                                |                        |                  |          |
| Car<br>No.                             | Engine Parameter Response, $\partial e_i / \partial p_i$ |                     |                                |                        |                  |          |
|                                        | Timing<br>g./m/deg                                       | Idle RPM<br>g/m/rpm | PCV<br>g/m/in.H <sub>2</sub> O | Air Cleaner<br>g/m/deg | Idle CO<br>g/m/% | Air Pump |
| 601                                    | 0.121*                                                   | 0.0013              | -                              | -0.0014                | -0.02/-0.05      | 0.11     |
| 602                                    | 0.066*                                                   | -0.0005             | -                              | -0.0041*               | 0.51/-0.10       | - 0.75*  |
| 603                                    | 0.162*                                                   | -0.0018             | -2.16*                         | -0.00053               | -0.90/0.62*      | -        |
| 604                                    | 0.091*                                                   | 0.0019*             | -0.82*                         | -0.0079*               | 0.36/-0.15*      | -        |
| 605                                    | 0.09*                                                    | -0.00009            | -0.16                          | -0.0019                | 0.10/-0.16       | -        |
| 606                                    | 0.202*                                                   | 0.0018              | -2.00                          | 0.00018                | -0.16/0.013      | -        |
| 607                                    | 0.055*                                                   | -0.00027            | 0.22                           | -0.0018*               | -0.21/0.15       | -        |
| 608                                    | 0.128*                                                   | -0.00056            | -2.67*                         | -0.004                 | 0.10/-0.187      | -        |
| 609                                    | 0.156*                                                   | 0.0018              | -2.04                          | -0.00277               | 0.00/0.65        | -        |
| 610                                    | 0.096*                                                   | 0.00085             | -                              | -0.00205               | 0.46/-0.35       | - 0.02   |
| 611                                    | 0.226*                                                   | -0.0016             | -0.20                          | -0.00161               | -1.4/0.41        | -        |

\*Statistically significant at the 90 per cent confidence level.

appear to be less sensitive than other vehicles. The extremely low sensitivity of the 1970 vehicle (605) does not appear to have a reasonable physical interpretation. Additional data on this vehicle are given in the subsection on diagnostic modes. Aside from this vehicle, the remaining power trains lie between responses of 4.9 to 11.9 ppm of HC per degree of timing.

Similarly with idle rpm, only vehicle 608 had an HC response significantly less than the test population. Responses of the remaining vehicles were between -0.35 and -1.0 ppm per rpm.

All statistically significant responses to a plugged PCV were positive, i.e., HC emissions were increased as flow restriction (crank case pressure) increased. The average increase was approximately 84 ppm per inch of water. Similarly, emissions increases resulting from restricted air cleaner are positive, an average value being 0.347 ppm per degree for those vehicles with statistically significant responses.

The effect of idle CO was evaluated at three levels to assess non-linear influences. The change in emissions in going from the low-to-nominal and nominal-to-high values of the parameter are both shown. Only a few responses were statistically significant. Six of the vehicles had negative responses at the low range of the idle CO setting indicating that the manufacturer's idle F/A ratio specifications are near the minimum value for HC emissions.

Air injection system malfunctions have a significant influence on emissions; HC increases by 112 to 217 ppm. The effectiveness index indicates that even when emissions are adjusted to the 10% failure rate indicated on the parameter survey study, the reduction is a substantial 15 ppm. The cost of repair, although large, may be cost effective because of the high leverage in reduction (see Volume II).

Mass emissions (Table 4-1b) show the same general trends as composite HC. There are some relative changes in parameter effects. For example, timing has nearly twice the percentage effect on composite emissions as on mass emissions. Idle rpm has approximately twice the percentage effect on composite emissions relative to mass emissions. Air injection system equipped vehicles mass emissions, 601, 602 and 610, were as sensitive to this system failure as were composite.

#### 4.1.2 CO Emissions Response

CO composite emissions are relatively unresponsive to idle rpm and only slightly so to basic timing (Table 4-2a). Increasing idle rpm slightly increased composite emissions. On approximately one-half of the vehicles, CO decreased with spark advance; 4 out of 6 at the statistically significant emission responses decreased with spark advance.

PCV had a consistently large influence, increasing emissions by 0.71 to 2.5% per inch of water when restricted as indicated by the statistically significant responses.

Significant CO emission responses to air cleaner blockage were measured on eight of the vehicles. Responses to this malfunction showed the largest range in response, 0.00006 to 0.016%, of any of the parameters selected. This malfunction will be discussed in a subsection on air cleaner test results.

Idle CO effects on composite CO emissions are again shown as two slopes connecting the three levels measured in the experiment. As demonstrated, the results indicate nonlinear effects as the slopes of the two line segments usually differ by factors of two or greater. Five vehicles, 603, 605, 606, 608 and 611, deviate from this statement. The preferred curve fit through these data was a single straight line. Three vehicles (602, 604 and 610) have negative slopes at the low level of idle CO setting. Two of these vehicles (602 and 610) were air injection system vehicles from two different manufacturers. Low level negative responses at lean idle F/A ratios for these vehicles may be due to an optimum mixture of combustibles in the exhaust manifold.

CO response to a disconnected airpump was always substantial, 1.27 to 1.76% increases were typical.

#### 4.1.3 NO Emissions Response

The predominant parameter affecting composite NO emissions is basic timing although changing the fuel-to-air ratio by large deviations in induction system parameters can also affect these emissions (Table 4-3a).

The NO response to timing ranged between 20 and 64 ppm per degree of crank. The timing effect is largely one of suppressing combustion gas residence time and peak temperature. Vehicle 605, which showed significantly less HC response to timing, also had one of the lower NO responses. All vehicles had emission responses to timing which were statistically significant.

The next most significant and prevalent parameter affecting NO were PCV valve restriction. This influence is attributable to rich carburetion and the attendant reduction in peak combustion temperature in the highly loaded modes. These are precisely the modes which predominate in weighting the composite NO emissions. If this is the case, we should anticipate that there would be a one-for-one correlation between CO and NO emissions. It was shown that those vehicles whose CO emission responses were statistically significant also had NO emission responses of opposite sign which were statistically significant. The exceptions to this statement are vehicles 603, which had relatively small, positive air cleaner restriction responses to both CO and NO, and 608, which was extremely sensitive to CO, but not to NO. The above trends are generally substantiated in their mass emission responses as well. The most significant exception is vehicle 611 which had the strongest CO mass emission response to air cleaner blockage, but only a small non-significant NO mass emission response, Figure 4-3b. The demonstrated inverse relationship will be used to develop a correlation between composite CO and NO emissions for each power train using the air cleaner experimental data (see Volume II).

On an average, timing effects had a slightly stronger influence on mass emissions than on composite. The opposite was true with regard to HC emission responses.

#### 4.1.4 Emission Diagnostic Signatures

The diagnostic mode (signature) emission responses developed from the definitive orthogonal experiment are presented in Tables 4-4 through 4-9



Table 4-4. HC Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 601 (AIR)                                                  |        |          |           |             |         |
|--------------------------------------------------------------------|--------|----------|-----------|-------------|---------|
| 90 Percent Confidence Level and Above *                            |        |          |           |             |         |
| Change in Emission, $\Delta E$ , Low to High Parameter Level (ppm) |        |          |           |             |         |
| Mode                                                               | Timing | Idle rpm | Air Pump  | Air Cleaner | Idle CO |
| Idle F                                                             | 166.14 | -111.42  | - 214.88  | -           | 55.15   |
| Idle C                                                             | 165.88 | -112.91  | - 244.06  | -           | 49.99   |
| 30-15F                                                             | 302.49 | -369.03  | - 518.86  | -           | -       |
| 50-20F                                                             | 491.42 | -1435.56 | - 1499.39 | -           | 354.96  |
| 1500 rpm                                                           | 143.49 | -94.34   | -         | -           | 64.45   |
| 30 F                                                               | 104.28 | -        | -164.93   | -           | -       |
| 33 C                                                               | 82.17  | -        | -158.16   | -           | -       |
| 0-25 F                                                             | 144.65 | -38.38   | -135.51   | -           | -       |
| 15-30 F                                                            | 129.64 | -        | -114.29   | -           | -       |
| 50 C                                                               | 92.05  | -        | -40.22    | -           | -       |
| WOT                                                                | 87.34  | -        | -157.99   | -           | -       |

C = Clayton  
F = Federal

\* see Table 3-1 for parameter levels set

Table 4-5. CO Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 601 (AIR)                                                                       |         |          |          |             |         |       |
|-----------------------------------------------------------------------------------------|---------|----------|----------|-------------|---------|-------|
| 90 Percent Confidence Level and Above                                                   |         |          |          |             |         |       |
| Change in Emission, $\Delta E$ , Low to High Parameter Level ( $\delta'$ ) <sup>*</sup> |         |          |          |             |         |       |
| Mode                                                                                    | Timing  | Idle rpm | Air Pump | Air Cleaner | Idle CO |       |
| Idle F                                                                                  | -       | -        | 4.310    | -           | -       | 2.145 |
| Idle C                                                                                  | - 0.777 | -        | - 4.981  | -           | -       | 2.070 |
| 30-15 F                                                                                 | -       | -        | - 5.543  | -           | -       | 1.378 |
| 50-20 F                                                                                 | - 0.539 | 0.443    | - 5.509  | -           | -       | 1.107 |
| 1500 rpm                                                                                | -       | -0.463   | - 5.421  | -           | -       | 1.934 |
| 30 F                                                                                    | 0.246   | -        | - 2.128  | -0.318      | -       | 0.408 |
| 33 C                                                                                    | -       | -        | - 1.439  | -0.609      | -       | -     |
| 0-25 F                                                                                  | 0.351   | -        | - 1.257  | -           | -       | 0.390 |
| 15-30F                                                                                  | -       | -        | - 1.066  | -0.268      | -       | 0.364 |
| 50 C                                                                                    | 0.373   | -        | -        | -0.298      | -       | -     |
| WOT                                                                                     | -       | -        | -1.780   | -0.361      | -       | 0.440 |

C = Clayton

F = Federal

C = Clayton  
F = Federal

\* see Table 3-2 for parameter levels set

Table 4-6. NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

| Mode     | Vehicle 601 (AIR)                                                  |          |          |             |
|----------|--------------------------------------------------------------------|----------|----------|-------------|
|          | 90 Percent Confidence Level and Above                              |          |          |             |
|          | Change in Emission, $\Delta E$ , Low to High Parameter Level (ppm) | Idle rpm | Air Pump | Air Cleaner |
| Timing   |                                                                    |          |          | Idle CO     |
| Idle F   | -                                                                  | 22.80    | -        | -           |
| Idle C   | -                                                                  | 19.86    | - 19.05  | -           |
| 30-15 F  | 57.01                                                              | -        | - 36.45  | -           |
| 50-20 F  | 182.79                                                             | -        | - 64.83  | -           |
| 1500 rpm | -                                                                  | -        | - 29.95  | -           |
| 30 F     | 327.02                                                             | -        | - 107.77 | 82.04       |
| 33 C     | 627.58                                                             | -        | - 247.43 | 270.13      |
| 0-25 F   | 509.67                                                             | -        | - 87.86  | -           |
| 15-30 F  | 569.46                                                             | -        | - 181.98 | -           |
| 50 C     | 1275.76                                                            | -        | - 204.04 | -           |
| WOT      | 550.53                                                             | -        | - 181.84 | 117.30      |
|          |                                                                    |          |          | - 148.11    |

C = Clayton

F = Federal

Table 4-7. HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode     | Vehicle 603 (EM)                                                    |        |          |     |             |
|----------|---------------------------------------------------------------------|--------|----------|-----|-------------|
|          | 90 Percent Confidence Level and Above                               |        |          |     |             |
|          | Change in Emission, $\Delta E$ , Low to High Parameter Level* (ppm) | Timing | Idle rpm | PCV | Air Cleaner |
| Idle F   | 178                                                                 | -95    | -        | -   | 67          |
| Idle C   | 154                                                                 | -75    | -        | -   | 73          |
| 30-15 F  | -                                                                   | -431   | -        | -   | -           |
| 50-20 F  | 431                                                                 | -1604  | -206     | -   | 235         |
| 1500 rpm | 142                                                                 | -110   | -        | -   | 85          |
| 30 F     | 111                                                                 | -18    | -        | -   | -           |
| 33 C     | 77                                                                  | -31    | -23      | -   | 23          |
| 0-25 F   | 154                                                                 | -46    | -19      | -   | 25          |
| 15-30 F  | 118                                                                 | -23    | -18      | -   | 15          |
| 50 C     | 52                                                                  | -      | -15      | -   | -           |
| WOT C    | 94                                                                  | -      | -        | -   | -           |

C = Clayton  
F = Federal

\* see Table 3-1 for parameter levels set

Table 4-8. CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode     | Vehicle 603 (EM)                                                 |        |          |        |         |
|----------|------------------------------------------------------------------|--------|----------|--------|---------|
|          | 90 Percent Confidence Level and Above *                          |        |          |        | Idle CO |
|          | Change in Emission, $\Delta E$ , Low to High Parameter Level (%) | Timing | Idle rpm | PCV    |         |
| Idle F   | -                                                                | -      | -        | -0.257 | 2.507   |
| Idle C   | -                                                                | -      | -        | -      | 1.952   |
| 30-15 F  | -0.177                                                           | 0.535  | -        | -0.179 | 1.662   |
| 50-20 F  | -                                                                | 0.671  | 0.295    | -      | 1.785   |
| 1500 rpm | -                                                                | 0.153  | -        | -      | 2.860   |
| 30 F     | 0.036                                                            | 0.114  | -0.192   | -      | 0.126   |
| 33 C     | 0.133                                                            | -      | -0.439   | -      | -       |
| 0-25 F   | -                                                                | 0.196  | -0.385   | -      | 0.412   |
| 15-30 F  | -                                                                | 0.144  | -0.410   | -      | 0.172   |
| 50 C     | -                                                                | -      | -0.250   | -      | -       |
| WOT C    | 0.098                                                            | -      | -0.313   | 0.116  | 0.151   |

C = Clayton  
F = Federal

\* see Table 3-2 for parameter levels set

Table 4-9. NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 603 (EM)                                                   |                 |            |                    |                |
|------------|--------------------------------------------------------------------|-----------------|------------|--------------------|----------------|
|            | 90 Percent Confidence Level and Above                              |                 |            |                    |                |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level (ppm) |                 |            |                    |                |
|            | <u>Timing</u>                                                      | <u>Idle rpm</u> | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |
| Idle F     | -                                                                  | 37              | -          | -                  | 32             |
| Idle C     | 19                                                                 | 43              | -          | -                  | -              |
| 30-15 F    | 214                                                                | -48             | -          | -                  | -              |
| 50-20 F    | 157                                                                | -63             | -          | -                  | -              |
| 1500 rpm C | -                                                                  | 17              | 7          | -                  | -              |
| 30 F       | 1098                                                               | -               | -          | -                  | -              |
| 33 C       | 1076                                                               | -80             | 276        | 74                 | -12            |
| 0-25 F     | 928                                                                | -               | 202        | -                  | -              |
| 15-30 F    | 1024                                                               | -47             | 233        | -51                | -45            |
| 50 C       | 1039                                                               | -               | 247        | -116               | -              |
| WOT C      | 1091                                                               | -               | 164        | -106               | -              |

C = Clayton  
F = Federal



for representative AIR and EM vehicles and in Appendix B, organized by generic classes of power train loading. General conclusions from the screening experiment, Section 3, are still valid. The following additional comments are significant:

- An indication of the precision of the orthogonal experiment is exhibited by the response of Federal mode idle CO (engine modification vehicles) to idle CO settings; values ranged between 2.15 and 2.65. The actual test value range was always 2.5%.
- The Clayton mode idle position in their cycle (i.e., last in the sequence of key modes) usually correlated within 10% of the Federal idle mode CO, indicating little carry-over effects from the transition deceleration mode.
- A failed air injection system slightly increased NO on two of the three AIR vehicles, possibly because no exhaust dilution occurred.
- Rich carburetion, as indicated by CO caused by PCV or air cleaner restrictions, always reduced NO in the highly loaded modes.
- The fast idle (1500 rpm) is essentially performed with the idle circuits of the carburetor as indicated by the mode CO response to idle CO (i.e., the fast idle response is approximately equal to the idle CO response).

#### 4.2 EMISSIONS STABILITY TESTS AND EXPERIMENTAL ERROR

Data summaries for the emissions stability tests are presented in Tables 4-10 and 4-11 for composite and mass emissions, respectively. These tests represent the chronological history of the base-line vehicle emissions over the period of the statistically designed experiment. Therefore, they should reflect the general noise in the statistically designed experiment because of vehicle emission instability and procedural errors (i.e., correlate with the residual error of the orthogonal experiments).

The residual error,  $S_{RE}$ , from the orthogonal test correlated well with the standard error of the stability tests. There were four instances,

**Table 4-10. Emissions Stability Tests**  
**Composite Emissions**

|     |    | STABILITY TESTS (Table 4-13) |          |          |          | $\bar{u}$ | $S_{ST}$ | $S_{RE}$ |
|-----|----|------------------------------|----------|----------|----------|-----------|----------|----------|
|     |    | <u>A</u>                     | <u>B</u> | <u>C</u> | <u>D</u> |           |          |          |
| 601 | HC | 247                          | 264      | 274      | 328      | 278       | 35       | 49       |
|     | CO | 2.24                         | 1.93     | 2.21     | 2.08     | 2.11      | 0.14     | 0.35     |
|     | NO | 908                          | 920      | 784      | 991      | 900       | 86       | 117      |
| 602 | HC | 412                          | 416      | 409      | 440      | 419       | 14.1     | 20       |
|     | CO | 1.65                         | 1.70     | 1.59     | 2.42     | 1.84      | .389     | .23      |
|     | NO | 1313                         | 1315     | 1416     | 1231     | 1319      | 75.7     | 78       |
| 603 | HC | 339                          | 215      | 297      | 296      | 287       | 51.9     | 27       |
|     | CO | 1.15                         | 0.99     | 0.97     | 0.97     | 1.02      | .087     | .08      |
|     | NO | 1585                         | 836      | 1615     | 1774     | 1453      | 419      | 71       |
| 604 | HC | 178                          | 168      | 176      | 182      | 176       | 5.88     | 49       |
|     | CO | 2.21                         | 1.27     | 1.76     | 1.95     | 1.798     | .397     | 0.99     |
|     | NO | 607                          | 867      | 974      | 666      | 779       | 171.4    | 126      |
| 605 | HC | 208                          | 194      | 210      | 662      | 318       | 229      | 163      |
|     | CO | 0.87                         | 1.25     | 1.29     | 1.22     | 1.15      | .194     | 0.28     |
|     | NO | 1012                         | 832      | 786      | 710      | 835       | 128      | 115      |
| 606 | HC | 355                          | 444      | 407      | 453      | 418       | 44.5     | 34       |
|     | CO | 1.28                         | 0.81     | 0.70     | 1.35     | 1.04      | .328     | 0.16     |
|     | NO | 2782                         | 4265     | 2886     | 2670     | 3151      | 798      | 128      |
| 607 | HC | 333                          | 331      | 553      | 438      | 414       | 105.4    | 95       |
|     | CO | 3.0                          | 2.9      | 3.2      | 2.7      | 2.95      | .208     | 0.22     |
|     | NO | 1058                         | 1294     | 1236     | 1575     | 1297      | 215      | 129      |
| 608 | HC | 250                          | 223      | 222      | 204      | 225       | 19.0     | 19       |
|     | CO | 1.06                         | 0.76     | 0.77     | 0.80     | .85       | .143     | 0.17     |
|     | NO | 1638                         | 2068     | 1640     | 1567     | 1728      | 229      | 106      |
| 609 | HC | 173                          | 173      | 149      | 158      | 163       | 11.8     | 77       |
|     | CO | 1.33                         | 0.46     | 0.56     | 0.37     | .68       | .44      | 0.08     |
|     | NO | 800                          | 1009     | 1182     | 1222     | 1053      | 192      | 130      |
| 610 | HC | 163                          | 208      | 208      | 251      | 208       | 35.9     | 96       |
|     | CO | 0.87                         | 0.69     | 0.78     | 1.06     | .85       | .158     | 0.26     |
|     | NO | 1235                         | 1163     | 995      | 1214     | 1151      | 109      | 200      |
| 611 | HC | 183                          | 231      | 209      | 214      | 209       | 19.9     | 60       |
|     | CO | 1.02                         | 0.75     | 0.76     | 0.79     | .83       | .126     | 0.68     |
|     | NO | 1599                         | 1514     | 1592     | 1589     | 1574      | 39.9     | 255      |

$S_{ST}$  denotes standard error from stability test.

$S_{RE}$  denotes residual error from orthogonal test.

$\bar{u}$  denotes mean of runs A, B, C, and D.

Table 4-11. Emissions Stability Tests  
Mass Emissions

|     |    | STABILITY TESTS (Table 4-13) |      |      |      |           | $S_{ST}$ | $S_{RE}$ |
|-----|----|------------------------------|------|------|------|-----------|----------|----------|
|     |    | A                            | B    | C    | D    | $\bar{u}$ |          |          |
| 601 | HC | 4.06                         | 4.85 | 4.56 | 4.61 | 4.52      | .332     | 0.50     |
|     | CO | 49.7                         | 63.2 | 54.1 | 55.6 | 55.6      | 5.62     | 8.13     |
|     | NO | 2.55                         | 1.09 | 2.20 | 1.77 | 1.903     | .628     | 0.53     |
| 602 | HC | 2.34                         | 3.29 | 2.96 | 2.77 | 2.84      | .397     | 0.61     |
|     | CO | 22.5                         | 19.3 | 25.1 | 32.9 | 24.95     | 5.81     | 6.10     |
|     | NO | 3.37                         | 3.72 | 1.97 | 1.23 | 2.57      | 1.17     | 0.90     |
| 603 | HC | 4.61                         | 4.32 | 4.75 | 4.50 | 4.55      | .182     | 0.79     |
|     | CO | 24.0                         | 19.0 | 19.3 | 19.4 | 20.4      | 2.39     | 3.6      |
|     | NO | 6.18                         | 4.29 | 6.30 | 5.78 | 5.64      | .925     | 0.56     |
| 604 | HC | 5.05                         | 3.79 | 3.90 | 4.79 | 4.38      | .631     | 0.57     |
|     | CO | 61.1                         | 43.5 | 67.3 | 61.6 | 58.4      | 10.3     | 30.0     |
|     | NO | 3.16                         | 3.70 | 2.69 | 2.27 | 2.95      | .615     | 0.29     |
| 605 | HC | 3.76                         | 3.55 | 3.89 | 8.92 | 5.03      | 2.59     | 2.72     |
|     | CO | 18.1                         | 23.5 | 23.2 | 22.8 | 21.9      | 2.55     | 6.05     |
|     | NO | 4.13                         | 3.27 | 3.54 | 2.90 | 3.46      | .518     | 0.54     |
| 606 | HC | 6.39                         | 7.98 | 6.77 | 6.81 | 6.987     | .688     | 1.04     |
|     | CO | 36.5                         | 23.7 | 20.6 | 20.7 | 25.4      | 7.55     | 3.42     |
|     | NO | 9.26                         | 9.80 | 11.3 | 10.9 | 10.32     | .945     | 1.46     |
| 607 | HC | 3.0                          | 2.9  | 3.2  | 2.7  | 2.95      | .208     | 0.41     |
|     | CO | 39.5                         | 19.4 | 19.1 | 24.8 | 25.7      | 9.56     | 4.15     |
|     | NO | 1.7                          | 1.9  | 2.6  | 1.8  | 2.00      | .408     | 0.28     |
| 608 | HC | 4.13                         | 3.72 | 3.71 | 3.28 | 3.71      | .347     | 0.70     |
|     | CO | 20.6                         | 25.3 | 22.5 | 23.5 | 22.98     | 1.96     | 3.67     |
|     | NO | 6.23                         | 7.64 | 5.45 | 6.34 | 6.415     | .908     | 1.01     |
| 609 | HC | 3.29                         | 2.33 | 1.63 | 1.46 | 2.18      | .832     | 0.63     |
|     | CO | 32.0                         | 16.0 | 18.4 | 13.4 | 19.95     | 8.29     | 17.8     |
|     | NO | 3.75                         | 3.89 | 4.19 | 4.18 | 4.003     | .218     | 1.32     |
| 610 | HC | --                           | 3.55 | 3.54 | 4.82 | 3.975     | .601     | 0.75     |
|     | CO | 33.9                         | 21.0 | 27.2 | 26.1 | 27.05     | 5.31     | 8.51     |
|     | NO | 3.44                         | 3.34 | 3.54 | 4.00 | 3.58      | .292     | 0.50     |
| 611 | HC | 1.98                         | 1.63 | 1.86 | 1.82 | 1.825     | .145     | 0.24     |
|     | CO | 13.0                         | 14.9 | 17.7 | 17.8 | 15.85     | 2.32     | 8.25     |
|     | NO | 4.21                         | 5.64 | 6.66 | 3.44 | 4.99      | 1.442    | 1.65     |

$S_{ST}$  denotes standard deviation from stability test.

$S_{RE}$  denotes residual error from orthogonal test.

$\bar{u}$  denotes mean of runs A, B, C, and D.

mass emissions for vehicles 604, 606, 607 and 609, where vehicles had large standard errors in the stability tests although they were stable after the first test. Residual errors were nominal indicating that test "A" may have been anomalous. One case existed where residual error for NO mass emissions was high even though vehicle base line stability was indicated. There was only one instance where an extremely high residual error was not correlated with base line stability emissions, NO composite for vehicle 611.

In general, residual errors are greater than vehicle stability error. This is because other errors related to vehicle setup are also present. These stem from the precision and accuracy with which the adjustments in the orthogonal test are made.

Pooled estimates of the error for basic vehicle composite emissions stability are 27 ppm, 0.20%, and 128 ppm for HC, CO, and NO, respectively (Reference 8). Values exceeding these numbers by a factor of two must be considered high. On this basis, standard errors for four HC, two CO, and one NO composite emissions stability tests must therefore be considered high. The stability data show frequent increases of HC emissions with time, indicating that deterioration is occurring. This deterioration may be caused by engine deposit buildup. High average values of emissions occur because the levels of malfunction simulated tend to bias emissions to the high side (i.e., PCV, air cleaner cannot have negative levels of their parameter settings, only nominal or failed).

In summary, the experimental precision appears to be good, if not a substantial improvement, over the screening experiment. Most error anomalies are explained by extreme vehicle instability.

#### 4.3 AIR CLEANER TESTS

Air cleaner test results are shown in Figures 4-1 through 4-3 plotted against AC air cleaner tester measurement, calibrated to read in degrees. Only those vehicles indicated by the orthogonal experiment to have responses to this parameter were evaluated. Two of the vehicles were found to be unresponsive (Nos. 603 and 606). One vehicle, 611, had extreme composite CO sensitivity to air cleaner blockage indicated by a factor of 4.5 increase in CO over its nominal value of 0.8%. This sensitivity was reflected in the mass CO emissions as well.

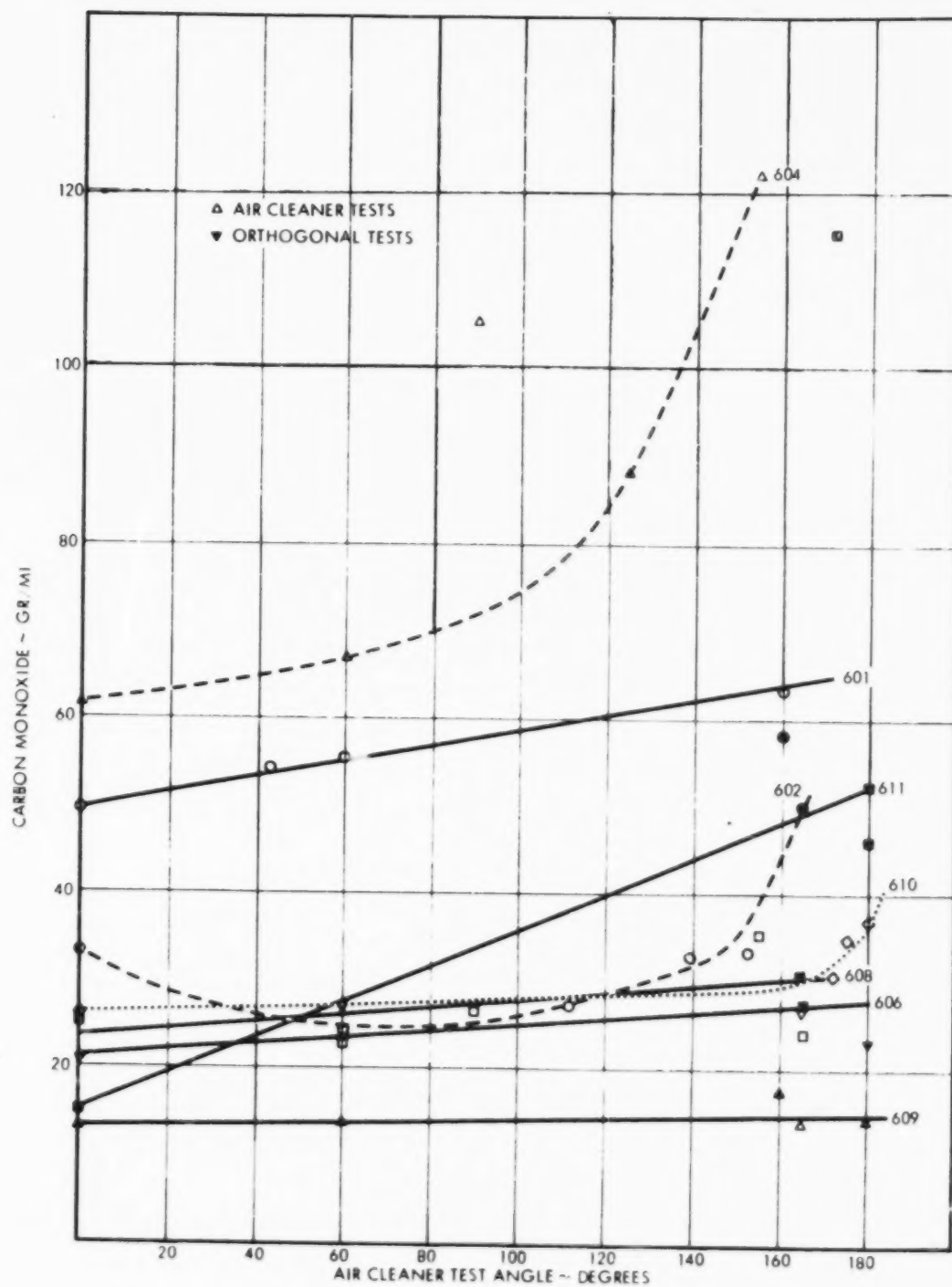


Figure 4-1. Effect of Air Cleaner Restriction on CO Mass Emissions

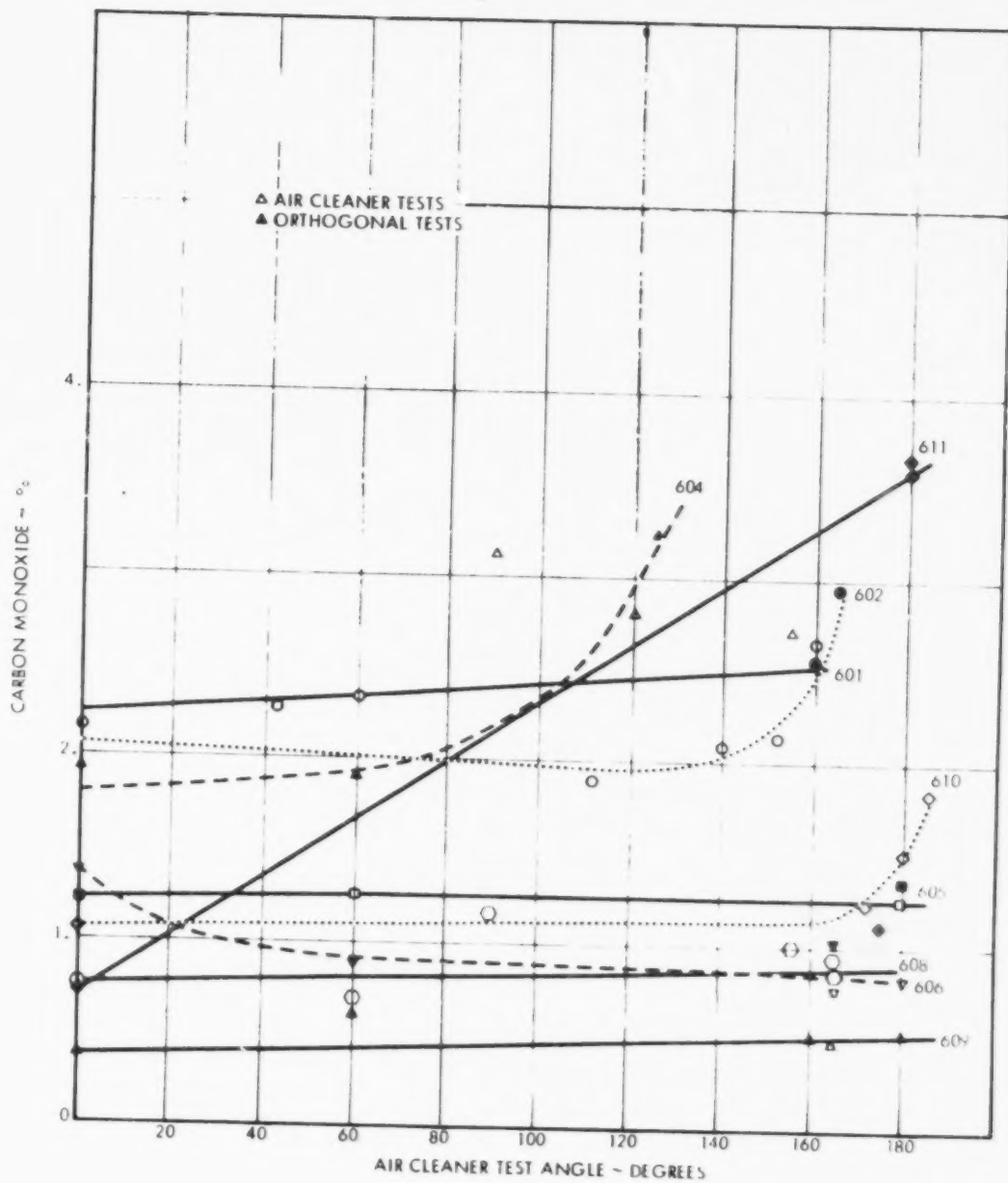


Figure 4-2. Effect of Air Cleaner Restriction on CO Composite Emissions



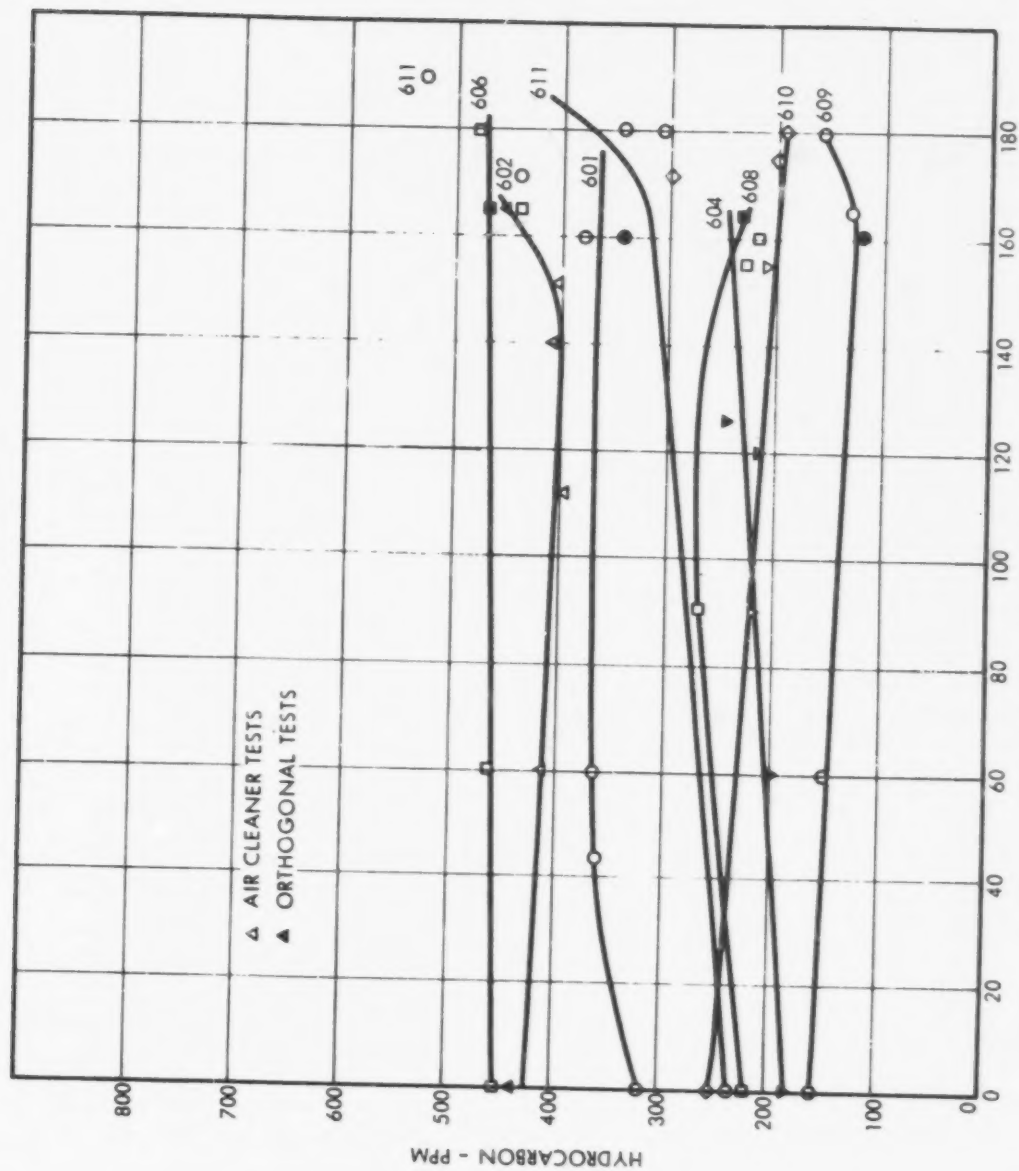


Figure 4-3. Effect of Air Cleaner Restriction on HC Composite Emissions

There appears to be no correlation with engine size or number of carburetor venturis. For example, both the largest (400 CID) and the smallest (91 CID) engines had extremely sensitive responses. The CO mass emissions measurements correlated very well with the composite values in both sensitivity and degree of linearity. Nonlinearities in both composite and mass emissions occurred much earlier for vehicle 604 than for the other vehicles with similar manifestations.

#### HC Emissions Response

HC emissions responses to air cleaner restriction showed considerably less sensitivity, Figure 4-3. For three vehicles small decreases in composite emissions were recorded. In only one instance (vehicle 611) was the emission response substantial in terms of percent increase over the nominal (unrestricted) condition. Nonlinearities did not occur in the emissions response until air cleaner test angles greater than 140 degrees were exceeded.

#### Correlation with Orthogonal Experiment

The emission level from the emissions stability tests and the emissions response from the statistically designed experiments were combined to provide an estimate of the total emissions resulting from a restricted air cleaner. The stability base line emission selected was that test which was the closest in chronological time to the air cleaner tests. Where the stability test indicated abnormal emissions variations, the mean value of the four stability runs was taken. These data are designated by a closed symbol in Figures 4-1 through 4-3. Agreement between the two tests was generally good, although vehicles 606 and 610 had considerable deviations in CO response and vehicles 601, 604 and 611 had large differences in HC. Most of these deviate vehicles had extremely large variances about their base line emissions which may partially explain these anomalies. In general, emissions data points from the statistically designed experiments lie on the linear portion of the air cleaner test data. The exceptions to this are vehicles 602 and 604 whose power trains comprise a small fraction of the population. In addition, after the first maintenance treatment, the tail of the parameter distribution curve, Figure 2-1, should be significantly reduced because of periodic, systematic maintenance. Therefore, to simplify

this parameter model in the economic effectiveness study, the linear responses from the statistically designed experiment were used.

The following conclusions were drawn:

- Strong, nonlinear responses occurred relatively infrequently and then, only in vehicles comprising a low percent of the population (i.e., air injection controlled or six cylinder power trains).
- Both composite and mass emissions show similar responses and nonlinearities to air cleaner restriction.
- A number of power trains, particularly Fords, showed little to no sensitivity to this malfunction, indicating that it may be possible to design around this influence.
- Significant emissions data scatter occurred in two power trains indicating possible local flow instabilities at critical pressure sensing points in the carburetor.

#### Air Cleaner Difficulties and Anomalies

CO emission response to air cleaner restriction did not occur on a large number of vehicles. This failure to respond was observed in both the screening and definitive experiments. It was also manifested in the initial attempts to set up the air cleaner restriction at the 50 mph road load condition.

It was determined that the restrictions created were of small magnitude as far as air density effects are concerned (i.e., only a few inches of water pressure drop). Thus, the mixture effects caused by the change in air density were insignificant. The air cleaner restriction action on fuel/air mixture is presumed to be caused by the variation of the fuel level because of the induced pressure in the fuel bowl. Fuel bowl pressure is determined by the pressure signal transmitted via the bowl vents, both internal and external. When external bowl vents are incorporated, they are usually open to ambient atmosphere at idle and off-idle modes. Thus, the majority

of carburetor operating modes are dependent on the effect of the internal bowl vents.

The conclusion is that the air cleaner restriction-created pressure drop is transmitted to the fuel bowl through the internal bowl vents with varying degrees of effectiveness on fuel/air in different vehicles. The variability of fuel/air response to air cleaner-induced pressure drop is inherent in the carburetor design. These design effects are the location of the internal bowl vents and the fuel metering response to fuel bowl pressure changes. The resultant fuel metering sensitivity to the design effects vary extensively across carburetor models and, to some extent, with major calibration differences on the same models.

#### 4.4 EXPERIMENTAL DESIGN

The following approach was used in designing the definitive experiment. A literature search was first performed to determine which, if any, parameters have nonlinear effects over the level to be tested. Those parameters indicated to affect nonlinear emission responses were idle CO and air pump flow restriction (Figure 4-4). Of the two, idle CO affected CO slightly and HC significantly. With regard to air injection systems, a nearly linear response of emissions to air flow is indicated in Reference 9. However, earlier work, Reference 10, is somewhat at variance with this statement. Our best interpretation of the failure data is that air injection systems are either performing nominally or are essentially flowing zero air. In this case, testing at two levels (nominal and disconnected) will yield results which directly apply without requiring interpolation for an actual flow rate condition. Therefore, the two levels of air injection system selected were its nominal and disconnected states.

In addition to the above parameters, the screening experiment indicated that two parameters investigated in this program were nonlinear. These were air cleaner blockage and misfire which were highly nonlinear in CO and slightly nonlinear in HC emissions, respectively (Figure 4-5).

Misfire was eliminated from further consideration for the following reasons:

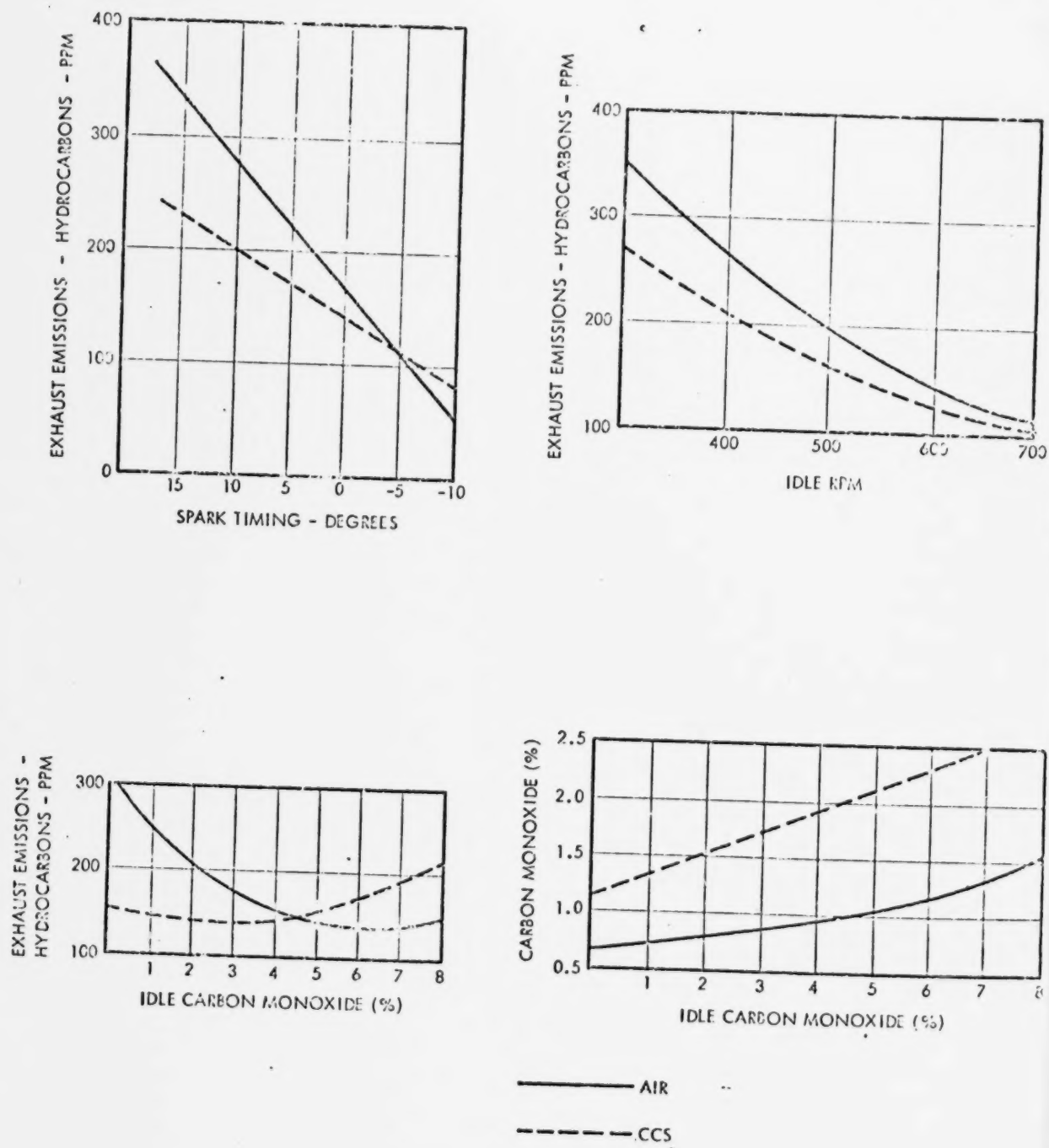


Figure 4-4. Emissions Responses to Idle Adjustments  
 California Air Resources Board, Reference 2

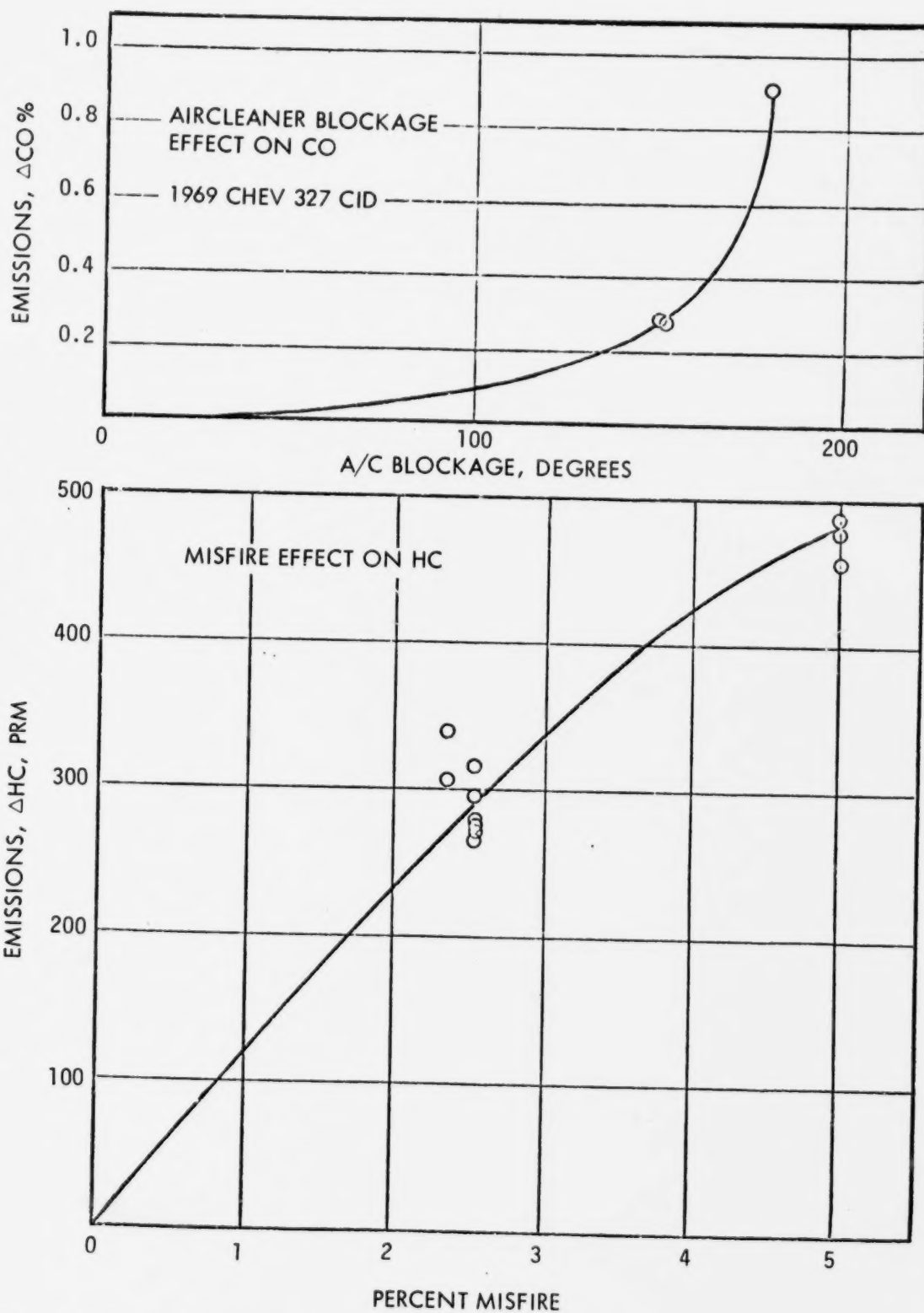


Figure 4-5. Nonlinear Emissions Responses to Malfunctions Screening Experiment  
4-28



- The resulting increase in HC emissions was causing NDIR instrument hangup and, therefore, a substantial increase in experimental error.
- Its effect is so strong that it was felt to be adequately characterized in the screening test.

### Statistical Design

The remaining parameters, their indicated nonlinearities, and the corresponding candidate experimental levels are shown in Table 4-12. Three fractional factorial experiments were considered which reflected varying mixes of parameters and levels. These were:

- Mixed level  $2^4 3^2$  designs where all highly nonlinear effects are evaluated and all parameters investigated.
- Mixed level  $2^4 3^1$  designs where the known idle CO nonlinearities are investigated at three levels. On vehicles equipped with air injection systems, the PCV is not to be tested.
- A two-level  $2^6$  where all parameters are to be investigated.

The  $2^4 3^1$  statistically designed experiment was selected on the basis that the air cleaner response was probably nearly linear over a large range of the variable. In addition, a substantial reduction in the number of tests could be achieved. The experimental design was obtained from Reference 11 and is shown in Table 4-13.

The diagnostic emission modes selected for Orthogonal Experiment No. 2 were a subset of those performed in the first experiment. It was determined from the first experiment that, when emission modes are generically classified to reflect the degree of engine loading, their diagnostic content is essentially identical. Therefore, the Federal modes, the key modes, a 1500 rpm no-load mode, and a wide-open throttle at 60 mph mode were selected as representative classes of diagnostic emissions modes.

### Air Cleaner Experiments

To characterize the nonlinear effects of air cleaner on emissions, a subexperiment was designed using three levels of blockage with all other

Table 4-12. Selection of Parameters and Their Levels

| Parameter                   | Population Reduction | Definitive Experiment |    | Candidate Experimental Designs |                                              |                  |
|-----------------------------|----------------------|-----------------------|----|--------------------------------|----------------------------------------------|------------------|
|                             |                      | Nonlinear Response    | HC | CO                             | 2 <sup>4</sup> 2 <sup>3</sup> 2 <sup>2</sup> | Levels Evaluated |
| Timing                      | 10.8 ppm             | -                     | -  | -                              | 2                                            | 2                |
| I rpm                       | 9.4 ppm              | L                     | L  | -                              | 2                                            | 2                |
| ICO                         | 0.61 %               | H                     | H  | L                              | 3                                            | 2                |
| A/C                         | 0.182 %              | -                     | -  | H                              | 3                                            | 2                |
| PCV                         | 0.062 %              | -                     | -  | -                              | 2                                            | 2                |
| Air Pump                    | 0.048 %              | -                     | -  | L                              | 2                                            | 2                |
| Total Tests at Two Levels   |                      |                       |    |                                |                                              |                  |
| Total Tests at Three Levels |                      |                       |    |                                |                                              |                  |
| Fractional Factorial        |                      |                       |    |                                |                                              |                  |
| Total Tests                 |                      |                       |    |                                |                                              |                  |
| L                           | low nonlinear        |                       |    |                                | 2 <sup>4</sup>                               | 2 <sup>6</sup>   |
| M                           | moderately nonlinear |                       |    |                                | 3 <sup>2</sup>                               | 3 <sup>1</sup>   |
| H                           | highly nonlinear     |                       |    |                                | 2/9                                          | 1/2              |
|                             |                      |                       |    |                                | 32                                           | 24               |
|                             |                      |                       |    |                                |                                              | 32               |

\* On vehicles equipped with air injection systems PCV is not to be tested.

Table 4-13. Orthogonal Test Matrix

| <u>Run</u> | <u>Timing</u> | <u>Idle<br/>rpm</u> | <u>PCV Valve<br/>or<br/>Air Pump</u> | <u>Air<br/>Cleaner</u> | <u>Idle<br/>CO</u> |
|------------|---------------|---------------------|--------------------------------------|------------------------|--------------------|
| <b>A*</b>  |               |                     |                                      |                        |                    |
| 1          | +7°           | +10%                | Open                                 | Open                   | +0.5%              |
| 2          | +7°           | -20%                | Open                                 | Restricted             | +2.0%              |
| 3          | +7°           | -20%                | Closed                               | Open                   | -0.5%              |
| 4          | -10°          | +10%                | Open                                 | Restricted             | -0.5%              |
| 5          | -10°          | +10%                | Open                                 | Restricted             | +0.5%              |
| 6          | +7°           | -20%                | Closed                               | Open                   | +2.0%              |
| 7          | -10°          | -20%                | Open                                 | Open                   | +2.0%              |
| 8          | +7°           | +10%                | Open                                 | Open                   | +2.0%              |
| <b>B*</b>  |               |                     |                                      |                        |                    |
| 9          | +7°           | -20%                | Open                                 | Restricted             | -0.5%              |
| 10         | -10°          | -20%                | Closed                               | Restricted             | +0.5%              |
| 11         | +7°           | -20%                | Closed                               | Open                   | +0.5%              |
| 12         | +7°           | +10%                | Closed                               | Restricted             | +2.0%              |
| 13         | -10°          | -20%                | Closed                               | Restricted             | +2.0%              |
| 14         | -10°          | -20%                | Closed                               | Restricted             | -0.5%              |
| 15         | +7°           | +10%                | Closed                               | Restricted             | -0.5%              |
| 16         | +7°           | +10%                | Open                                 | Open                   | -0.5%              |
| <b>C*</b>  |               |                     |                                      |                        |                    |
| 17         | -10°          | -20%                | Open                                 | Open                   | +0.5%              |
| 18         | +7°           | +10%                | Closed                               | Restricted             | +0.5%              |
| 19         | -10°          | +10%                | Open                                 | Restricted             | +2.0%              |
| 20         | -10°          | +10%                | Closed                               | Open                   | -0.5%              |
| 21         | -10°          | +10%                | Closed                               | Open                   | +2.0%              |
| 22         | -10°          | -20%                | Open                                 | Open                   | -0.5%              |
| 23         | -10°          | +10%                | Closed                               | Open                   | +0.5%              |
| 24         | +7°           | -20%                | Open                                 | Restricted             | +0.5%              |
| <b>D*</b>  |               |                     |                                      |                        |                    |

\* Vehicle Stability Tests at Manufacturers' Settings  
Run A is Cold Start Test After Tuneup

parameters set at manufacturer's specification. The air cleaner was blocked while operating the vehicle at 50 mph and the Federal load such that increases in mode CO of 0.25, 0.5, and 1.0 were obtained. The purpose of this procedure is to ensure that the composite emissions will respond with a finite change. An additional emissions test point was selected for the air cleaner blocked to register 60 degrees on the AC tester. This level was selected on the basis that it lies close to the parameter survey mean and yet is large enough to effect an emissions response. Blockage was measured using the AC tester for test settings made on the basis of CO at 50 mph.

#### Vehicle Emissions Stability Test

The screening experiments indicated that a combination of accumulated mileage and high average emissions were significant contributors to experimental error. To assess this contribution, vehicle emissions stability tests were performed at the end of the 8th, 16th, and 24th test. In each orthogonal series, these tests were run with the vehicle returned to manufacturer's specification. Both hot bag and equivalent 6th and 7th cycle mode emissions were obtained during these tests.

#### Power Train Selection

Eleven generic power trains were again studied in this experiment. At the recommendation of the Steering Committee, two of the power trains in the moderate sized V-8 classification were of 1970 vintage. The power train matrix is presented in Table 4-14. The power trains have been selected to: (1) reflect national sales of make, power train size, and model year, (2) reflect reasonable proportions of air reactor and engine modification controlled vehicles and, (3) duplicate, where possible, those power trains previously tested in the screening experiment.

### 4.5 DATA REDUCTION PROCEDURES

Data reduction procedures were upgraded for the definitive tests to reflect the more precise measurement requirements and new power train test matrix. These revisions were:

- Application of the 1968 composite emissions calculation procedure (i.e., dilution factor equal to  $14.5/(10.5 \text{ HC} + 0.5 \text{ CO} + \text{CO}_2)$ ).

Table 4-14. Definitive Orthogonal Experiment Power Train Attributes

| Vehicle No. | Make    | Model-Yr.  | CID  | Carb | Mileage | HC    | Composite Emissions |      |      |         |      |      |
|-------------|---------|------------|------|------|---------|-------|---------------------|------|------|---------|------|------|
|             |         |            |      |      |         |       | Pre-CO              | NO   | HC   | Post-CO |      |      |
| 601         | Chev    | Wagon      | 1967 | 327  | 4       | 54058 | 193                 | 1.94 | 430  | 248     | 2.24 | 908  |
| 602         | Ford    | Mustang    | 1966 | 289  | 2       | 37690 | 576                 | 2.24 | 859  | 412     | 1.65 | 1313 |
| 603         | Ford    | LTD        | 1969 | 429  | 2       | 18067 | 415                 | 2.19 | 1118 | 339     | 1.15 | 1585 |
| 604         | Pontiac | Firebird   | 1968 | 400  | 4       | 29246 | 489                 | 3.78 | 468  | 178     | 1.56 | 668  |
| 605         | Dodge   | Challenger | 1970 | 383  | 2       | 10818 | 178                 | .938 | 1236 | 208     | .870 | 1012 |
| 606         | Ford    | Torino     | 1969 | 302  | 2       | 21418 | 537                 | .430 | 2928 | 330     | 1.21 | 2865 |
| 607         | VW      | 1300       | 1969 | 91   | 1       | 15033 | 293                 | 2.48 | 1122 | 333     | 3.02 | 1058 |
| 608         | Plym    | Barracuda  | 1968 | 318  | 2       | 32096 | 277                 | 1.64 | 1703 | 213     | 1.06 | 1638 |
| 609         | Chev    | Impala     | 1970 | 350  | 2       | 13378 | 235                 | 1.18 | 997  | 156     | .913 | 858  |
| 610         | Chev    | Nova       | 1969 | 230  | 1       | 16480 | 314                 | .498 | 1255 | 163     | .87  | 1235 |
| 611         | Chev    | Chevelle   | 1969 | 250  | 1       | 22424 | 154                 | .58  | 1748 | 183     | 1.02 | 1599 |

- All deceleration modes read and averaged in equal 20-second increments.

The former modification was adopted to reflect the fact that 1970 vehicles were evaluated. The modified data reading procedure was adopted as a reasonable approximation to mode integration, and to reflect more accurately the nonlinear aspects of the CO calibration curves.

The data analysis, as with the screening experiment, consisted of a statistical analysis of the experimental data. Specifically, the following were calculated:

- Emissions response surfaces for mass, composite and diagnostic mode emissions
- Analysis of variances for emission response statistical significance
- Analysis of variances for parameter interactions.

A revised subroutine was written to perform the above analysis for a  $3^1 2^4$  statistical design. A typical data output display from this subroutine is presented in Table 4-15.

The data field in the right column of Table 4-15 displays the basic emission measurements in concentration units. Its primary use is to quickly evaluate the validity of the input data. The top, left data field is a computation of the mean emissions levels at the levels of the parameter settings, A through E. These data were calculated applying the orthogonality condition of the experimental design. A detailed analysis of the parameter evaluated at three levels (i.e., idle CO) is reported in the field immediately below. The interactions are shown for the two component parts of the main effect,  $E_1$  and  $E_2$ , (i.e., the two linear slopes connecting the three emission levels) and the remaining parameter main effects.

The second page summarizes the pertinent data from an analysis of variances calculation. The final two columns are of most importance for engineering considerations. The "F" ratio column and the degrees-of-freedom combine to form a statement of statistical confidence or the main effect. The "slope" column summarizes the response surfaces for parameters A-E,



Table 4-15. Federal Tests

| Car Number 602 CD<br>Mode 8 |        | Emission at Parameter Setting                                                   |                |                  |
|-----------------------------|--------|---------------------------------------------------------------------------------|----------------|------------------|
| Data Input Summary          |        | Means                                                                           |                |                  |
|                             |        | Low Level<br>-1                                                                 | Mid Level<br>0 | High Level<br>+1 |
| 1                           | 1.585  | A 2.892                                                                         |                | 2.935            |
| 2                           | 2.876  | B 3.162                                                                         |                | 2.664            |
| 3                           | 3.298  | C 3.547                                                                         |                | 2.280            |
| 4                           | 1.993  | D 3.317                                                                         |                | 2.509            |
| 5                           | 2.220  | E 2.829                                                                         | 2.765          | 3.146            |
| 6                           | 3.457  |                                                                                 |                |                  |
| 7                           | 2.092  |                                                                                 |                |                  |
| 8                           | 2.447  |                                                                                 |                |                  |
| 9                           | 3.144  |                                                                                 |                |                  |
| 10                          | 4.313  |                                                                                 |                |                  |
| 11                          | 3.183  |                                                                                 |                |                  |
| 12                          | 3.960  |                                                                                 |                |                  |
| 13                          | 4.379  |                                                                                 |                |                  |
| 14                          | 4.411  |                                                                                 |                |                  |
| 15                          | 3.701  |                                                                                 |                |                  |
| 16                          | 1.481  |                                                                                 |                |                  |
| 17                          | 2.193  |                                                                                 |                |                  |
| 18                          | 3.861  |                                                                                 |                |                  |
| 19                          | 2.723  |                                                                                 |                |                  |
| 20                          | 2.233  |                                                                                 |                |                  |
| 21                          | 3.233  |                                                                                 |                |                  |
| 22                          | 2.375  |                                                                                 |                |                  |
| 23                          | 2.535  |                                                                                 |                |                  |
| 24                          | 2.229  |                                                                                 |                |                  |
|                             |        | Regression Slopes<br>Interactions With E(E1, E2)                                |                |                  |
|                             |        | A                                                                               | B              | C                |
| E1                          | 0.089  |                                                                                 | 0.160          | 0.097            |
| E2                          | -0.127 |                                                                                 | 0.263          | -0.127           |
|                             |        |                                                                                 |                | D                |
|                             |        |                                                                                 |                | 0.052            |
|                             |        |                                                                                 |                | 0.092            |
|                             |        | Curve Fits For ICO                                                              |                |                  |
|                             |        | The Linear Fit Is                                                               |                |                  |
|                             |        | $Y = 2.822 + 0.137 * E$                                                         |                |                  |
|                             |        | The Quadratic Fit Is                                                            |                |                  |
|                             |        | $Y = 0.128 * E^{**2} + -0.065 * E + 2.765$                                      |                |                  |
|                             |        | A = Timing      D = Air Cleaner<br>B = Rpm          E = Idle CO<br>C = Air Pump |                |                  |

Table 4-15. Federal Tests (Continued)

| Car Number 602 CD<br>Mode 8 |                               |                         |                   |            |                                                                   |            |
|-----------------------------|-------------------------------|-------------------------|-------------------|------------|-------------------------------------------------------------------|------------|
| Analysis of Variances       |                               |                         |                   |            |                                                                   |            |
| Source<br>Variation         | D.F.<br>Degrees of<br>Freedom | SS<br>Sum of<br>Squares | MS<br>Mean<br>Sum | F<br>Ratio | Slope<br>$\frac{\Delta \text{Emission}}{\Delta \text{Parameter}}$ |            |
| Main Effects                |                               |                         |                   |            |                                                                   |            |
| A                           | 1                             | 1.134E-02               | 1.134E-02         | 0.218      |                                                                   | -2.557E-03 |
| B                           | 1                             | 1.49                    | 1.49              | 28.6       |                                                                   | -1.660E-02 |
| C                           | 1                             | 9.63                    | 9.63              | 185        |                                                                   | -1.27      |
| D                           | 1                             | 3.92                    | 3.92              | 75.4       |                                                                   | 1.62       |
| E                           | 2                             | 0.665                   | 0.333             | 6.40       |                                                                   | 0.137      |
| Two-Factor<br>Interaction   |                               |                         |                   |            |                                                                   |            |
| AB=CD                       | 1                             | 0.562                   | 0.562             | 10.8       |                                                                   | 0.153      |
| AC=BD                       | 1                             | 1.514E-03               | 1.514E-03         | 2.914E-02  |                                                                   | -7.944E-03 |
| AD=BD                       | 1                             | 4.671E-02               | 4.671E-02         | 0.899      |                                                                   | 4.412E-02  |
| AE                          | 2                             | 6.776E-02               | 3.388E-02         | 0.652      |                                                                   |            |
| BE                          | 2                             | 0.728                   | 0.364             | 7.00       |                                                                   |            |
| CE                          | 2                             | 7.044E-02               | 3.522E-02         | 0.678      |                                                                   |            |
| DE                          | 2                             | 8.524E-02               | 4.262E-02         | 0.820      |                                                                   |            |
| Residuals                   | 6                             | 0.312                   | 5.198E-02         |            |                                                                   |            |
| Totals                      | 23                            | 17.6                    |                   |            |                                                                   |            |
| E1                          | 1                             | 1.675E-02               | 1.675E-02         | 0.322      |                                                                   | 0.137      |
| E2                          | 1                             | 0.581                   | 0.581             | 11.2       |                                                                   | 0.254      |
| SS(L)                       | 1                             | 5.910E-02               | 5.910E-02         | 1.14       |                                                                   |            |
| SS(Q)                       | 1                             | 0.606                   | 0.606             | 11.7       |                                                                   |            |
| Effective Coefficients Are  |                               |                         |                   |            |                                                                   |            |
| A                           | B                             | C                       | D                 | E1         | E2                                                                | BYE        |
| -0.022                      | 0.149                         | -0.151                  | 64.012            | -0.241     | 0.945                                                             | 0.508      |

(i.e., change in emission level per unit change in parameter setting). The slope coefficients for those component failures which were simulated by making them inoperative (i.e., PCV and air pump) are the emission changes which result in going from the nominal to failed state. All other emission response surfaces are based on unit changes in the parameter. For example, the response surface for parameter A, timing deviation from manufacturers specification, is -0.0025% change in composite CO per one degree of advance of basic timing. This statement can only be made at a low level of confidence as reflected by a 0.218 value of "F". An "F" value of 2.5 is required to make a statement on slope at the 90% confidence level. That is, one out of ten times the measured effect may not be statistically significant.

#### 4.6 TEST PROCEDURES

##### 4.6.1 Vehicle Preparation

Preparation for the definitive experiment was basically the same as for the screening experiment, with each vehicle receiving an oil and filter change, "as received" cold start emission test, diagnostic inspection, engine tune-up, and after tune-up cold-start emission test. The vehicle was then instrumented for the orthogonal test series. For this series of tests, however, the idle percent CO was specified more definitively. Except for the Volkswagen, a member of each vehicle manufacturers' engineering staff was contacted to obtain the recommended idle percent CO setting. For General Motors Corporation vehicles, the emission idle setting specification decal procedure was the recommended procedure. This required only setting the carburetor mixture screws both with the aid of an engine tachometer to determine a required rpm drop and with a specific number of screw turns. The resulting idle percent CO on General Motors vehicles and the specified idle percent CO supplied by the other manufacturers were used as the null point for the idle percent CO deviations.

Section 3 describes the procedures used for the inspection and tune-up. As in the screening experiment, no special procedures for balancing the idle mixture screws were used. Occasionally some components, such as distributors and carburetors needed replacement, but new ones were sometimes

impossible to obtain on short notice. In these cases, the defective units were repaired in-house to maintain the close time scheduling of the program. This procedure was probably in the best interest of the program in that it provided more realistic data in relation to what could be expected in the field.

Efforts were made to ensure that air pump performance on air injection vehicles had been properly diagnosed. As part of the after tuneup inspection procedure, actual flow rates were measured in the manufacturer's recommended idle speed and at 50 mph using rounded entrance orifice meters. The system pressure was also measured at these engine speeds.

#### 4.6.2 Measurement and Special Test Equipment

The exhaust analysis equipment for the definitive experiment was the same as used for the screening experiment. The procedures used were nearly identical; only the "cold bag" constant volume, dilute sample was deleted since only two hot 7-mode emission cycles were required.

Two pyrometers were installed in each vehicle to monitor the engine temperature. One thermocouple was placed in the engine crankcase oil pan and one installed in the upper radiator hose. The misfire generator was not required.

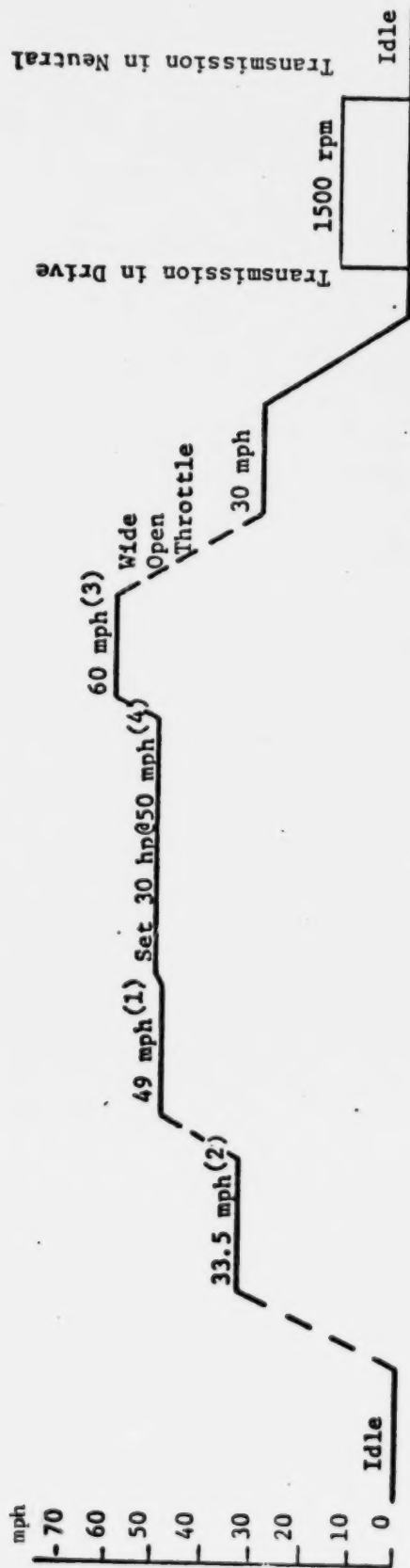
#### 4.6.3 Orthogonal Test Procedures

As in the screening experiment, the test procedure consisted of simultaneously and systematically setting five engine parameters to several levels and measuring the 7-mode exhaust emissions over two cycles, as well as collecting composite dilute bag samples. Emissions were also measured during several diagnostic short cycles which were found to be most effective for sensing malfunctions. Twenty-four tests were run on each vehicle, as specified in the statistical design, to quantify the effect of each parameter. The test matrix is shown in Table 4-13 and the short cycles in Figure 4-6. Three additional base line tests were run with all the parameters set to normal specifications. These tests served as an evaluation of the basic engine condition during the test series.

TABLE 4-16. Orthogonal Test

| Air Injection System--Pump<br>Flow Rates and System Pressure |                        |                |                        |               |
|--------------------------------------------------------------|------------------------|----------------|------------------------|---------------|
| <u>Car No.</u>                                               | <u>Pump Flow Rates</u> |                | <u>System Pressure</u> |               |
|                                                              | <u>Idle</u>            | <u>50 mph</u>  | <u>Idle</u>            | <u>50 mph</u> |
| 601                                                          | 37.8 lbs/hr            | 117.9 lbs./hr] | 0.4 in. Hg             | 4.6 in. Hg    |
| 602                                                          | 23.5 lbs/hr            | 72.3 lbs/hr    | 2.1 in. Hg             | 6.1 in. Hg    |
| 610*                                                         | 30.8 lbs/hr            | 85.5 lbs/hr    | 1.3 in. Hg             | 5.9 in. Hg    |

\*Flow rates checked at free flow.



#### 2800 to 3900 lb vehicles

- (1) 45 mph
- (2) 30 mph

#### Light Foreign Vehicles

- (1) 36 mph
  - (2) 23.5 mph
  - (3) 45 mph
  - (4) Set 5 hp @ 40 mph
- } 3rd Gear

Figure 4-6. Diagnostic Emission Modes Definitive Experiment



The five parameters were set in a sequence so that one particular setting was not affected by the subsequent setting of another. The sequence and procedure were as follows:

1. The ignition timing was set as specified in the test matrix, to either 7 degrees advanced or 10 degrees retarded from the manufacturers' specifications.
2. On engine modification controlled vehicles, the PCV hose was either normally open or completely closed. On air injection-controlled vehicles, the air pump was allowed to operate normally or the air distribution hoses disconnected and the distribution manifolds plugged immediately upstream of the check valves.
3. Either a new or restricted air cleaner element was installed in the air cleaner housing. The restricted elements were taped with five equally spaced vertical openings so that the observed percent CO at 50 mph road load was 0.5% CO greater than with the new element.
4. The idle rpm was set with the carburetor speed screw at either 10% above or 20% below the manufacturer's specification.
5. The idle percent CO was set to the desired deviation from the specification. The idle rpm was maintained at the desired setting and the engine temperature was kept constant. Deviations were +0.5% +2.0%, and -0.5% CO from specification.

Other than the modifications in short cycles shown in Figure 4-6, the Volkswagen did not require any additional modifications to the test plan. The restriction in the Volkswagen air cleaner was produced by draining the oil from the housing and taping closed a sufficient number of holes in the bottom of the filter media container. This produced the desired increase in percent CO.

#### 4.6.4 Air Cleaner Restriction Experiment

Four auxiliary air cleaner restriction tests were performed after completion of the main experiment. The vehicle was set back to manufacturers' specifications for these tests and air cleaner restrictions set at four different levels. The vehicle was then run on the same test cycle used for

the orthogonal experiment, two hot 7-mode cycles and the short cycles. The idle percent CO and rpm were reset to specification before each test. The restrictions used were based on the percent CO observed at 50 mph road load. For three of the tests, the air cleaner element was taped partially closed to produce 0.25%, 0.50%, and 1.00% CO increases over the percent CO obtained with a standard, unrestricted element. The fourth test was with the element restricted to produce a 60-degree reading (angular) on the AC air cleaner tester.

Air cleaner restriction was adjusted by taping the element so that there were five equal-area, vertical openings. The air cleaner element was always installed in the same position in the housing, and CO readings were made with the air pump disconnected on vehicles so equipped. Fifty mph CO readings were taken alternately with the standard and taped element during the setup to ensure a consistent increase in CO.

Several problems were encountered during these tests as the percent CO values proved unstable. Also, some vehicles did not show any response to the restriction up to 180-degree readings on the air cleaner tester. In these cases the restriction was set on the AC tester. When the desired higher restrictions were obtained on six cylinder engines, the idle CO was adversely affected by the restriction so that the desired percent CO could not be set.

#### 4.6.5 Test and Measurement Quality Control

Each vehicle's condition was maintained as consistently as possible throughout the program. Engine temperatures were held nearly constant for each test and while setting the idle CO. Both the engine coolant and oil temperature were monitored so that consistent warmup was obtained. The oil temperature proved to be most variable and was held to  $\pm 10$  degrees Fahrenheit whenever possible before each test. The target oil temperature was determined by driving consecutive 7-mode cycles until the temperature stabilized. Before each test, the vehicle was driven at 40 mph until the desired oil temperature was reached. The idle CO settings were made by first warming up the vehicle to the desired temperature and then setting the mixture and speed without prolonged idle periods.

Table 4-16. System Cross Check Results  
Orthogonal Experiment

| <u>Bottle No.</u> | <u>Labeled Gas Concentration</u> | <u>Observed Value System No. 1</u> | <u>Observed Value System No. 2</u> |
|-------------------|----------------------------------|------------------------------------|------------------------------------|
| 2                 | 57.6 ppm NO <sub>2</sub>         | 58 ppm                             | 55 ppm                             |
| 3                 | 77.5 ppm NO <sub>2</sub>         | 70 ppm                             | 69 ppm                             |
| 4                 | 3460 ppm NO                      | 3270 ppm                           | 3274 ppm                           |
| 5                 | 890 ppm NO                       | 865 ppm                            | 935 ppm                            |
| 6                 | 8596 ppm Hexane                  | 8536 ppm                           | 8613 ppm *                         |
| 7                 | 4332 ppm Hexane                  | 4429 ppm                           | 4243 ppm *                         |
| 8                 | 1004 ppm Hexane                  | 1003 ppm                           | 989 ppm                            |
| 8                 | 7.91% CO                         | 7.37%                              | 7.62%                              |
| 8                 | 13.9% CO <sub>2</sub>            | 13.5%                              | 13.4%                              |
| 9                 | 294 ppm Hexane                   | 295 ppm                            | 298 ppm                            |
| 9                 | 2.00% CO                         | 1.97%                              | 2.03%                              |
| 9                 | 7.32% CO <sub>2</sub>            | 7.61% (1)                          | 7.00% *                            |

\* Indicates that correction was made for instrument drift.

The same precautions taken with the instrument systems on the screening experiment were used on this experiment. In addition, with the elimination of the misfire generator, the hydrocarbon hangup was always maintained to within one chart division on the low hydrocarbon recorder. Weekly preventive maintenance schedules were instituted to assure system consistency throughout the experiment. A monthly system crosscheck (Table 4-16) was also performed to assure close agreement between the two dynamometer systems used in the experiment.

Precautions were taken to ensure proper setup and maintenance of the parameter deviations. In addition to the idle setting procedure described above, the idle consistency was assured for the short cycles by running them immediately after the 7-mode cycles. The intervening short cycles required only 4 minutes, allowing sufficient time to obtain emissions measurements from the bag samples. Parameter setting checklists recorded actual values of the settings required and provided space for the driver to list the attained values. Check sheets were used for both the orthogonal experiment and the air cleaner restriction experiment. Quality of the engine tune-up was assured by repeating the diagnostic inspection after tune-up.

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APPENDIX A

SCREENING EXPERIMENT  
DATA SUMMARY

1966 Chevrolet Impala  
327 cubic inch engine  
air reactor  
Car 501

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> |
|-----------|-----------------|---------------|
| Timing    | 137.4           | 0.0           |
| Vac. Adv. | 6.1             | 0.32          |
| Pt. Res.  | 108.6           | 0.07          |
| Misfire   | 487.8           | 0.17          |
| ICO       | -158.4          | 0.57          |
| IRPM      | -145.7          | -0.12         |
| Float     | -15.5           | -0.83         |
| A/C       | 148.2           | 0.37          |
| PCV       | 53.4            | 0.23          |
| Air Pump  | -108.3          | 0.55          |
| Leak      | 88.7            | -0.65         |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | norm      |
| Pt. Res.  | nom       | high      |
| Misfire   | 0         | 5%        |
| ICO       | -0.5      | 3.0       |
| IRPM      | -100      | 100       |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 180       |
| PCV       | 0         | 100%      |
| Air Pump  | 0         | 100%      |
| Leak      | 0         | 3.0 cfm   |

Effectiveness Coefficient

|          |             |            |
|----------|-------------|------------|
| Timing   | 7.276*      |            |
| Misfire  | 66.345****  |            |
| ICO      | -168.3527** | 0.61586*** |
| IRPM     | 6.558*      |            |
| A/C      | 32.613*     | 0.08096**  |
| Air Pump |             | 0.05322**  |
| Float    |             | -0.044***  |
| Leak     |             | -0.015***  |

\* 90% confidence level  
\*\* 95% confidence level  
\*\*\* 99% confidence level  
\*\*\*\* 999% confidence level

1968 Ford Custom  
302 cubic inch engine  
engine modification  
Car 502

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> |
|-----------|-----------------|---------------|
| Timing    | 247.6           | 0.06          |
| Vac. Adv. | -132.1          | 0.12          |
| Pt. Res.  | -55.2           | 0.26          |
| Misfire   | 472.3           | -0.04         |
| ICO       | -137.3          | 0.42          |
| IRPM      | -93.9           | 0.09          |
| Float     | 81.9            | -0.56         |
| A/C       | -54.3           | 1.15          |
| PCV       | 63.3            | 0.47          |
| Leak      | 176.5           | -0.15         |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | norm      |
| Pt. Res.  | 0         | 1         |
| Misfire   | 0         | 5%        |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 180       |
| PCV       | 0         | 100%      |
| Leak      | 0         | 1.0 cfm   |

Effectiveness Coefficients

|         |            |              |
|---------|------------|--------------|
| Timing  | 13.107***  |              |
| Misfire | 64.238**** |              |
| ICO     | -204.345*  | 0.63746***** |
| A/C     |            | 0.25190***** |
| PCV     |            | 0.05638***** |
| Float   |            | -0.030***    |
| Leak    | 12.2**     |              |

1968 Dodge Charger

318 cubic inch engine  
engine modification  
Car 503

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> |
|-----------|-----------------|---------------|
| Timing    | 40.0            | -0.83         |
| Vac. Adv. | 178.0           | 0.10          |
| Pt. Res.  | 61.6            | -0.11         |
| Misfire   | 454.0           | 0.06          |
| ICO       | -55.0           | 0.29          |
| IRPM      | -16.0           | 0.08          |
| Float     | 61.7            | -0.62         |
| A/C       | -122.5          | 1.74          |
| PCV       | -2.6            | 1.33          |
| Leak      | 142.8           | -0.47         |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | norm      |
| Pt. Res.  | 0         | 1         |
| Misfire   | 0         | 5%        |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 180       |
| PCV       | 0         | 100%      |
| Leak      | 0         | 1.0 cfm   |

Effectiveness Coefficients

|         |             |              |
|---------|-------------|--------------|
| Misfire | 61.744 **** |              |
| A/C     | -26.951 *   | 0.38311 **** |
| PCV     |             | 0.15775 **** |
| Timing  |             |              |
| ICO     |             | 0.426*       |
| Leak    | 9.8*        | -0.032**     |
| Float   |             | -0.033**     |

1967 Mercury Cougar

289 cubic inch engine

air reactor

Car 504

Emissions Change ( $\Delta E$ )

|            | <u>HC (ppm)</u> | <u>CO (%)</u> |
|------------|-----------------|---------------|
| Timing     | 221.8           | 0.06          |
| Vac. Adv.  | 24.3            | 0.17          |
| Pt. Res.   | 34.2            | 0.10          |
| Misfire    | 335.0           | 0.13          |
| ICO        | -17.0           | 0.43          |
| IRPM       | -76.5           | -0.58         |
| Float      | -8.5            | -0.30         |
| A/C        | -49.8           | 0.16          |
| PCV        | -30.8           | 0.24          |
| A. P. Res. | 14.1            | 0.29          |
| Leak       | -40.6           | -0.19         |

Parameter Adjustment Range ( $\Delta P$ )

|               | <u>-1</u> | <u>+1</u> |
|---------------|-----------|-----------|
| Timing        | -10       | 7         |
| Vac. Adv.     | 0         | norm      |
| Pt. Res.      | 0         | 1         |
| Misfire       | 0         | 2.38%     |
| ICO           | -0.5      | 2.0       |
| IRPM          | -100      | 50        |
| Float         | -1/8 in.  | 1/4 in.   |
| A/C           | 0         | 180       |
| PCV           | 0         | 100%      |
| Air Pump Res. | 0         | 100%      |
| Leak          | 0         | 1.0 cfm   |

Effectiveness Coefficients

|            |            |              |
|------------|------------|--------------|
| Timing     | 11.742**** |              |
| Misfire    | 95.700**** |              |
| ICO        |            | 0.64639***** |
| IRPM       | 4.591**    |              |
| PCV        |            | 0.02863**    |
| A. P. Res. |            | 0.02815**    |
| Float      |            | -0.016**     |
| Leak       |            | -0.013*      |

1966 Ford Mustang  
200 cubic inch engine  
air reactor  
Car 505

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|---------------|------------------|
| Timing    | 103.1541        | -0.2681       | 888.8230         |
| Vac. Adv. | 0.3471          | 0.1391        | 243.2337         |
| Pt. Res.  | -6.6966         | 0.1081        | -298.7855        |
| Misfire   | 314.2517        | -0.1638       | 282.2089         |
| ICO       | -8.9888         | 0.2494        | 129.2298         |
| IRPM      | -36.0851        | 0.1350        | 162.1784         |
| Float     | 2.5048          | -0.2863       | 196.7137         |
| A/C       | -37.7114        | -0.0502       | 195.7326         |
| PCV       | 58.3604         | 0.2089        | -53.1603         |
| AP. Res.  | 36.1094         | 0.2907        | -225.3394        |
| Leak      | -5.9232         | -0.1292       | 15.0771          |

Effectiveness Coefficients

|           |           |           |           |
|-----------|-----------|-----------|-----------|
| Timing    | 5.46**    | -0.0142** | 47.06**** |
| Vac. Adv. | -0.01     | -0.0037   | -6.49**** |
| Misfire   | 83.47**** | -0.0435   | 74.96**** |
| ICO       | -13.38    | 0.371**   | 192.29*   |
| IRPM      | 2.17      | -0.0081   | -9.73**   |
| Float     | 0.13      | -0.0153** | 10.49**   |
| A/C       | -8.30     | -0.0110   | 43.06**   |
| PCV       | 6.94      | 0.0249*   | -6.33     |
| AP. Res.  | 3.47      | 0.0279**  | -21.63*** |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | norm      |
| Pt. Res.  | 0         | 1         |
| Misfire   | 0         | 2.56%     |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 180       |
| PCV       | 0         | 100%      |
| AP. Res.  | 0         | 100%      |
| Leak      | 0         | 0.66 CFM  |



1968 Oldsmobile 98  
455 cubic inch engine  
engine modification  
Car 506

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|---------------|------------------|
| Timing    | 116.0798        | -0.3360       | 255.3430         |
| Vac. Adv. | 107.2582        | -0.2844       | 235.5440         |
| Pt. Res.  | -9.4096         | -0.0328       | 182.6096         |
| Misfire   | 303.9252        | -0.0402       | 85.4532          |
| ICO       | 64.0126         | -0.1114       | 107.6542         |
| IRPM      | -140.3498       | 0.0802        | 54.3650          |
| Float     | -8.3228         | -0.8246       | 151.2648         |
| A/C       | -23.9320        | 0.6038        | -120.0864        |
| PCV       | -47.0052        | 0.3102        | -23.4012         |
| Leak      | -72.1054        | -0.5918       | 110.3088         |

Effectiveness Coefficients

|           |           |             |          |
|-----------|-----------|-------------|----------|
| Timing    | 6.14****  | -0.0178**   | 13.51*** |
| Vac. Adv. | -1.78**** | 0.0047**    | -3.91*** |
| Pt. Res.  | -8.78     | -0.0306     | 170.54** |
| Misfire   | 86.83**** | -0.0115     | 24.41    |
| ICO       | 95.25**   | 0.1658      | 160.19   |
| IRPM      | 8.42****  | -0.0048     | -3.26    |
| Float     | -0.44     | -0.0440**** | 8.06*    |
| A/C       | -5.68     | 0.1431****  | -28.48   |
| PCV       | -5.59*    | 0.0369**    | -2.78    |
| Leak      | -3.30***  | -0.0271**** | 5.05     |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | 24        |
| Pt. Res.  | 350%      | 250%      |
| Misfire   | 0         | 2.38%     |
| ICO       | -0.5      | 2.0%      |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 167       |
| PCV       | 0         | 100%      |
| Leak      | 0         | 1.5 CFM   |

1968 Chevrolet Malibu  
327 cubic inch engine  
engine modification  
Car 507

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (ppm)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|-----------------|------------------|
| Timing    | 246.1237        | 0.1215          | 524.3278         |
| Vac. Adv. | 21.5766         | 0.0389          | 130.8063         |
| Pt. Res.  | 51.4207         | -0.0305         | 17.1489          |
| Misfire   | 273.5788        | 0.1825          | 6.2426           |
| ICO       | -13.3314        | 0.6232          | -90.5837         |
| IRPM      | -212.3738       | -0.1258         | 81.8173          |
| Float     | -37.3743        | -0.5219         | 104.9185         |
| A/C       | 23.5502         | 0.2684          | -99.3739         |
| PCV       | 62.2087         | 0.3825          | -190.7897        |
| Leak      | 132.8349        | -0.1463         | 84.9297          |

Effectiveness Coefficients

| Timing    | 13.03**** | 0.0064      | 27.76**** |
|-----------|-----------|-------------|-----------|
| Vac. Adv. | -0.54     | -0.0010     | -3.27**   |
| Pt. Res.  | 33.25     | -0.0197     | 11.09     |
| Misfire   | 72.67**** | 0.0485**    | 1.66      |
| ICO       | -19.84    | 0.9273****  | -134.79*  |
| IRPM      | 12.74***  | 0.0075      | -4.91     |
| Float     | -1.99     | -0.0278**** | 5.60**    |
| A/C       | 6.10      | 0.0695***   | -25.72    |
| PCV       | 7.40      | 0.0455****  | -22.70*** |
| Leak      | 8.46**    | -0.0093*    | 5.41      |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | norm      |
| Pt. Res.  | 400%      | 250%      |
| Misfire   | 0         | 2.56%     |
| ICO       | -0.5      | 2.0%      |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 1530      |
| PCV       | 0         | 100%      |
| Leak      | 0         | 1.08 CFM  |

1966 Dodge Polara  
383 cubic inch engine  
engine modification  
Car 508

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|---------------|------------------|
| Timing    | 180.30          | -0.6875       | 564.15           |
| Vac. Adv. | 107.18          | -0.4802       | 530.27           |
| Pt. Res.  | -31.94          | 0.0030        | 191.44           |
| Misfire   | 296.13          | -0.0373       | 256.74           |
| ICO       | -97.57          | 0.3329        | -93.72           |
| IRPM      | -71.57          | 0.1266        | -41.74           |
| Float     | -17.00          | -0.8237       | 178.30           |
| A/C       | -22.69          | 0.5069        | -113.02          |
| PCV       | 28.35           | 0.3146        | -171.09          |
| Leak      | -10.55          | -0.0546       | 36.81            |

Effectiveness Coefficients

|           |            |             |           |
|-----------|------------|-------------|-----------|
| Timing    | 9.55****   | -0.0364**** | 29.87**** |
| Vac. Adv. | -1.59***   | 0.0071***   | -7.86**** |
| Pt. Res.  | 1.92       | -0.0002     | -11.49**  |
| Misfire   | 78.66****  | -0.0099     | 68.20***  |
| ICO       | -145.18*** | 0.4954**    | -139.46   |
| IRPM      | 4.29**     | -0.0076     | 2.50      |
| Float     | -0.91      | -0.0439**** | 9.51**    |
| A/C       | -5.45      | 0.1216***   | -27.12    |
| PCV       | 3.37       | 0.0374**    | -20.36**  |
| Leak      | -0.57      | -0.0030     | 2.01      |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | 27        |
| Pt. Res.  | 300       | 250       |
| Misfire   | 0         | 2.56      |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 165       |
| PCV       | 0         | 100       |
| Leak      | 0         | 1.27      |

1969 Chevrolet Nova  
230 cubic inch engine  
air reactor  
Car 509

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|---------------|------------------|
| Timing    | 280.40          | -0.2461       | 411.93           |
| Vac. Adv. | 58.62           | -0.0875       | 120.41           |
| Pt. Res.  | 11.53           | -0.0454       | -32.37           |
| Misfire   | 264.56          | 0.0734        | 72.79            |
| ICO       | -35.82          | 0.2928        | -3.09            |
| IRPM      | -256.86         | 0.2844        | -64.15           |
| Float     | -17.33          | -0.4437       | 154.47           |
| A/C       | 29.28           | 0.1106        | 18.51            |
| PCV       | 31.64           | 0.7059        | -247.13          |
| Air Pump  | 59.31           | 0.5079        | -86.80           |
| Leak      | 23.51           | -0.0417       | 40.36            |

Effectiveness Coefficients

|           |           |            |            |
|-----------|-----------|------------|------------|
| Timing    | 14.84**** | -0.0130    | 21.81****  |
| Vac. Adv. | -1.02*    | 0.0015     | -2.09**    |
| Pt. Res.  | 7.36      | -0.0290    | 20.67      |
| Misfire   | 70.27**** | 0.0195     | 19.33      |
| ICO       | -53.30    | 0.4356*    | -4.60      |
| IRPM      | 15.41**** | -0.0171*   | 3.85       |
| Float     | -0.92     | -0.0237**  | 8.24**     |
| A/C       | 6.55      | 0.0247     | 4.14       |
| PCV       | 3.77      | 0.0840**** | -29.41**** |
| Air Pump  | 5.69*     | 0.0488***  | -8.33      |
| Leak      | 2.13      | -0.0038    | 3.66       |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | 16        |
| Pt. Res.  | 250       | 167       |
| Misfire   | 0         | 2.56      |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 177       |
| PCV       | 0         | 100       |
| Air Pump  | 0         | 100       |
| Leak      | 0         | 0.76 CFM  |

1968 Ford Ranchero  
390 cubic inch engine  
engine modification  
Car 510

Emissions Change ( $\Delta E$ )

|           | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NOX (ppm)</u> |
|-----------|-----------------|---------------|------------------|
| Timing    | 308.83          | 0.0034        | 571.41           |
| Vac. Adv. | 267.66          | 0.0279        | 677.43           |
| Pt. Res.  | 142.68          | -0.0084       | -18.83           |
| Misfire   | 220.59          | 0.0891        | -27.40           |
| ICO       | -288.31         | 0.5648        | -70.23           |
| IRPM      | -217.28         | 0.0942        | 10.47            |
| Float     | 92.41           | -0.3214       | 128.52           |
| A/C       | 97.67           | 0.0692        | -26.73           |
| PCV       | 99.38           | 0.4758        | -161.69          |
| Leak      | 247.35          | -0.0236       | 48.71            |

Effectiveness Coefficients

|           |            |             |             |
|-----------|------------|-------------|-------------|
| Timing    | 16.35***   | 0.0002      | 30.25*****  |
| Vac. Adv. | -5.63***   | -0.0006     | -14.26***** |
| Pt. Res.  | -83.60     | 0.0049      | 11.03       |
| Misfire   | 58.59**    | 0.0237      | -7.28       |
| ICO       | -429.01*** | 0.8405***** | -104.50     |
| IRPM      | 13.04**    | -0.0057     | -0.63       |
| Float     | 4.93       | -0.0171***  | 6.85**      |
| A/C       | 21.49      | 0.0152      | -5.88       |
| PCV       | 11.83      | 0.0566      | -19.24***   |
| Leak      | 13.21**    | -0.0013     | 2.60        |

Parameter Adjustment Range ( $\Delta P$ )

|           | <u>-1</u> | <u>+1</u> |
|-----------|-----------|-----------|
| Timing    | -10       | 7         |
| Vac. Adv. | 0         | 19        |
| Pt. Res.  | 378       | 250       |
| Misfire   | 0         | 2.56      |
| ICO       | -0.5      | 2.0       |
| IRPM      | -100      | 50        |
| Float     | -1/8 in.  | 1/4 in.   |
| A/C       | 0         | 180       |
| PCV       | 0         | 100       |
| Leak      | 0         | 1.29      |

APPENDIX B

DEFINITIVE EXPERIMENT  
DATA SUMMARY



COMPOSITE EMISSIONS  
Car 601

YEAR: 1967      MAKE: Chevrolet      CID: 327      EMISS. DEV: Air

Emission Changes

|                  | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|------------------|-----------------|---------------|-----------------|
| A    Timing      | 181*            | 0.32*         | 522*            |
| B    Idle rpm    | -95*            | 0             | 22              |
| C    Air Pump    | -155*           | -1.765*       | 29              |
| D    Air Cleaner | -8              | -0.26         | 68              |
| E    Idle CO     | 18.6/0.66       | 0.15/0.45*    | -14/-130*       |
| Residuals        | 49              | 0.35          | 117             |

Parameter Adjustments

|                | <u>-1</u>                   | <u>0</u> | <u>+1</u>           |
|----------------|-----------------------------|----------|---------------------|
| Timing         | 4 <sup>0</sup> ATDC         |          | 13 <sup>0</sup> BTC |
| Idle rpm       | 480                         |          | 660                 |
| Air Pump       | Plugged                     |          | Normal              |
| ** Air Cleaner | Plugged (160 <sup>0</sup> ) |          | Normal              |
| Idle CO        | 5.5%                        | 6.5%     | 8.0%                |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AC = BD            |           | 0.162*    |           |
| AD = BC            |           | -0.176*   |           |
| BE1                |           | 0.404*    | 51.3*     |
| BE2                |           | -0.107*   |           |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter level change,  $\Delta P = -1$  to provide computer usage sign convention compatibility.

MASS EMISSIONS  
Car 601

YEAR: 1967 MAKE: Chevrolet CID: 327 EMISS. DEV: Air

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 1.05*                   | -9.85*                 | 2.05*                  |
| B | Idle rpm    | -1.38*                  | -0.32                  | 0.23                   |
| C | Air Pump    | -3.14*                  | -22.64*                | -0.11                  |
| D | Air Cleaner | -0.281                  | -2.10                  | 0.23                   |
| E | Idle CO     | 0.852/-0.201*           | 3.46/-7.89             | -0.02/-0.08            |
|   | Residuals   | 0.50                    | 8.13                   | 0.53                   |

|    |             | <u>Parameter Adjustments</u> |          |           |
|----|-------------|------------------------------|----------|-----------|
|    |             | <u>-1</u>                    | <u>0</u> | <u>+1</u> |
|    | Timing      | 4° ATDC                      |          | 13° BTDC  |
|    | Idle rpm    | 480 rpm                      |          | 660 rpm   |
| ** | Air Pump    | Plugged                      |          | Normal    |
|    | Air Cleaner | Plugged (160°)               |          | Normal    |
|    | Idle CO     | 5.5%                         | 6.5%     | 8%        |

|                    |           | <u>Interactions</u> |           |
|--------------------|-----------|---------------------|-----------|
| <u>Interaction</u> | <u>HC</u> | <u>CO</u>           | <u>NO</u> |
| AD = BC            | 0.344*    |                     | 0.23*     |
| AE1                |           | 12.46*              |           |
| AE2                |           | -0.043*             |           |
| BE1                | 0.716*    |                     |           |
| BE2                | -0.520*   |                     |           |
| CE1                | 0.149*    | 8.35*               |           |
| CE2                | -0.818*   | 0.325*              |           |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter level change,  $\Delta P = -1$  to provide computer usage sign convention compatibility.

COMPOSITE EMISSIONS  
Car 602

YEAR: 1966

MAKE: Ford

CID: 289

EMISS. DEV: Air

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 175.5*          | 0.043         | 506.2*          |
| B | Idle rpm    | -61.3*          | -0.498*       | 57.4*           |
| C | Air Pump    | -112.2*         | -1.267*       | 180.9*          |
| D | Air Cleaner | -19.8*          | -0.808*       | 206.2*          |
| E | Idle CO     | -1.9/20.3       | -0.064/0.381* | 66.1/-75.7      |
|   | Residuals   | 20              | 0.228         | 78              |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u> |
|-------------|----------------|----------|-----------|
| Timing      | 10° ATDC       |          | 7° BTDC   |
| Idle rpm    | 440            |          | 600       |
| ** Air Pump | Plugged        |          | Normal    |
| Air Cleaner | Plugged (165°) |          | Normal    |
| Idle CO     | 3.1%           | 4.1%     | 5.6%      |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            | -10.3*    |           |           |
| AD = BC            | 12.7*     |           | 31.2*     |
| AC = BD            |           |           | 40.4*     |
| AE1                |           |           | -94.2*    |
| AE2                |           |           | 112.1*    |
| BE1                | -18.1*    | 0.160*    | -34.5*    |
| BE2                | 27.2*     | 0.263*    | -120.3*   |
| CE1                |           |           | -141.5*   |
| CE2                |           |           | 52.9*     |
| DE1                |           |           | 45.9*     |
| DE2                |           |           | -99.1*    |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter level change  $\Delta P = -1$  to provide computer usage sign convention compatibility.

MASS EMISSIONS  
Car 602

YEAR: 1966

MAKE: Ford (Mustang)

CID: 289

EMISS. DEV: Air

Emission Changes

|               | <u>HC (grams/mile)</u> | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
|---------------|------------------------|------------------------|------------------------|
| A Timing      | 1.51*                  | -4.00                  | 1.12*                  |
| B Idle rpm    | -0.87*                 | -1.37                  | 0.08                   |
| C Air Pump    | -1.02*                 | -22.84*                | 0.75*                  |
| D Air Cleaner | -0.36                  | -18.27*                | 0.67*                  |
| E Idle CO     | -0.13/0.29             | 1.50/8.51*             | 0.51/-0.15             |
| Residuals     | 0.61                   | 6.1                    | 0.90                   |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u> |
|-------------|----------------|----------|-----------|
| Timing      | 10° ATDC       |          | 7° BTDC   |
| Idle rpm    | 440 rpm        |          | 600 rpm   |
| **Air Pump  | Plugged        |          | Normal    |
| Air Cleaner | Plugged (165°) |          | Normal    |
| Idle CO     | 3.1%           | 4.1%     | 5.6%      |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            | 0.440*    | 5.21*     |           |
| AC = BD            | -0.336*   |           |           |
| AD = BC            | 0.452*    | -2.63*    |           |
| AE1                |           |           | -0.715*   |
| AE2                |           |           | 1.096*    |
| BE1                | -0.748*   |           |           |
| BE2                | 0.61*     |           |           |
| CE1                |           | 1.26*     |           |
| CE2                |           | -9.24*    |           |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter level change,  $\Delta P = -1$  to provide computer usage sign convention compatibility.

COMPOSITE EMISSIONS  
Car 603

YEAR: 1969

MAKE: Ford

CID: 429

EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 146.5*          | -0.007        | 913.2*          |
| B | Idle rpm    | -113.9*         | 0.246*        | -81.7*          |
| C | PCV         | -22.7*          | 0.327*        | 205.2*          |
| D | Air Cleaner | -10.1           | -0.080*       | -70.3*          |
| E | Idle CO     | -0.4/39.7*      | 0.287/0.286*  | -130.5/76.6*    |
|   | Residuals   | 87              | 0.082         | 71              |

Parameter Adjustments

|             | <u>-1</u>                   | <u>0</u> | <u>+1</u>                         |
|-------------|-----------------------------|----------|-----------------------------------|
| Timing      | 4 <sup>0</sup> ATDC         |          | 13 <sup>0</sup> BTDC              |
| Idle rpm    | 440                         |          | 600                               |
| PCV         | Plugged                     |          | Normal**                          |
| Air Cleaner | Plugged (130 <sup>0</sup> ) |          | (-0.45 inches of water)<br>Normal |
| Idle CO     | 2.3%                        | 3.3%     | 4.8%                              |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u>                  | <u>NO</u> |
|--------------------|-----------|----------------------------|-----------|
| AB = CD            | 12.1*     | 3.938 x 10 <sup>-2</sup> * |           |
| AD = BC            |           | 3.780 x 10 <sup>-2</sup> * |           |
| AC = BD            |           |                            | 59.1*     |
| BE1                |           | 0.068*                     |           |
| BE2                |           | 0.058*                     |           |
| DE1                |           |                            | 112.1*    |
| DE2                |           |                            | -93.4*    |

\*Statistically significant at 90 per cent confidence level.

\* Parameter change in inches of water-crankcase pressure suction.

# MASS EMISSIONS

Car 603

YEAR: 1969

MAKE: Ford (LTD)

CID: 429

EMISS. DEV: E.M

## Emission Changes

|               | <u>HC (grams/mile)</u> | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
|---------------|------------------------|------------------------|------------------------|
| A Timing      | 0.79*                  | -4.10*                 | 2.76*                  |
| B Idle rpm    | -1.39*                 | 8.25*                  | -0.29                  |
| C PCV         | -0.46                  | -1.03                  | 0.97*                  |
| D Air Cleaner | 0.09                   | -1.10                  | 0.07                   |
| E Idle CO     | -0.02/0.38             | 6.23/7.09*             | -0.90/0.93*            |
| Residuals     | 0.79                   | 3.6                    | 0.56                   |

## Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u>                           |
|-------------|----------------|----------|-------------------------------------|
| Timing      | 4° ATDC        |          | 13° BTDC                            |
| Idle rpm    | 440 rpm        |          | 600 rpm                             |
| PCV         | Plugged        |          | Normal**<br>(-0.45 inches of water) |
| Air Cleaner | Plugged (130°) |          | Normal                              |
| Idle CO     | 2.3%           | 3.3%     | 4.8%                                |

## Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AC = BD            |           |           | 0.40*     |
| BE1                | 1.2*      |           |           |
| BE2                | -0.7*     |           |           |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter change in inches of water-crankcase pressure suction.



COMPOSITE EMISSIONS  
Car 604

YEAR: 1968      MAKE: Pontiac      CID: 400      EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 168.5*          | 0.130         | 341.5*          |
| B | Idle rpm    | -69.0*          | 0.192         | 42.9            |
| C | PCV         | -22.2           | -1.128*       | 143.3*          |
| D | Air Cleaner | -65.0*          | -1.296*       | 204.8*          |
| E | Idle CO     | -52.4/24.0      | -0.089/0.608  | 12.7/-80.0      |
|   | Residuals   | 49              | 0.99          | 126             |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u>                         |
|-------------|----------------|----------|-----------------------------------|
| Timing      | 1° ATDC        |          | 16° BTDC                          |
| Idle rpm    | 520            |          | 715                               |
| PCV         | Plugged        |          | Normal**                          |
| Air Cleaner | Plugged (126°) |          | (-0.45 inches of water)<br>Normal |
| Idle CO     | 1.6%           | 2.6%     | 4.1%                              |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            | -22.7*    |           |           |
| DE1                | 31.3*     |           |           |
| DE2                | 33.9*     |           |           |

\*Statistically significant at 90 per cent confidence level.

\*\* Parameter change in inches of water-crankcase pressure suction.

MASS EMISSIONS  
Car 604

YEAR: 1968

MAKE: Pontiac (Firebird) CID: 400

EMISS. DEV: E.M.

|           |             | <u>Emission Changes</u> |                        |                        |
|-----------|-------------|-------------------------|------------------------|------------------------|
|           |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A         | Timing      | 2.04*                   | -20.00                 | 1.54*                  |
| B         | Idle rpm    | -1.30*                  | 5.86                   | 0.37*                  |
| C         | PCV         | -0.49*                  | -27.56*                | 0.37*                  |
| D         | Air Cleaner | -1.04*                  | -30.49*                | 1.00*                  |
| E         | Idle CO     | -0.68/+0.50*            | 0.176/24.21            | 0.36/-0.22*            |
| Residuals |             | 0.57                    | 30.01                  | 0.29                   |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 1° ATDC        |          | 16° BTDC  |
| Idle rpm                     | 520 rpm        |          | 715 rpm   |
| PCV                          | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (126°) |          | Normal    |
| Idle CO                      | 1.6%           | 2.6%     | 4.1%      |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AB = CD             | -0.32*    |           | -0.18*    |
| AD = BC             | 0.27*     |           | 0.19*     |
| AE1                 |           |           | 0.73*     |
| AE2                 |           |           | -0.12*    |
| CE1                 |           |           | -0.68*    |
| CE2                 |           |           | 0.11*     |
| DE1                 | 0.21*     |           | -0.32*    |
| DE2                 | 0.62*     |           | 0.37*     |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 605

YEAR: 1970

MAKE: Dodge

CID: 383

EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 49.6            | -0.348*       | 562.2*          |
| B | Idle rpm    | -137.8*         | 0.364*        | -87.5*          |
| C | PCV         | 53.9            | -0.068        | -47.2           |
| D | Air Cleaner | 33.3            | -0.194        | -45.7           |
| E | Idle CO     | -132.3/-67.9*   | 0.396/0.317*  | -51.0/66.4      |
|   | Residuals   | 163             | 0.28          | 115             |

Parameter Adjustments

|             | <u>-1</u>        | <u>0</u> | <u>+1</u> |
|-------------|------------------|----------|-----------|
| Timing      | 7.5 ATDC         |          | 9.5 BTDC  |
| Idle rpm    | 520              |          | 725       |
| PCV         | Plugged          |          | Normal    |
| Air Cleaner | Plugged (180° +) |          | Normal    |
| Idle CO     | 0.5%             | 1.5%     | 3.0%      |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AD = BC            |           |           | 55.4*     |
| BE1                |           | 0.46*     |           |
| BE2                |           | -0.11*    |           |

\*Statistically significant at 90 per cent confidence level.

\*\*Parameter level change,  $\Delta P = -1$  to provide computer usage sign convention compatibility.

MASS EMISSIONS  
Car 605

YEAR: 1970 MAKE: Dodge CID: 383 EMISS. DEV: E.M.

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 0.28                    | -12.09*                | 1.53*                  |
| B | Idle rpm    | -1.84                   | 8.70*                  | -0.02                  |
| C | PCV         | 0.75                    | -0.55                  | 0.07                   |
| D | Air Cleaner | 0.32                    | -5.97*                 | 0.35                   |
| E | Idle CO     | -1.76/-0.73             | 8.06/6.31*             | 0.10/-0.24             |
|   | Residuals   | 2.72                    | 6.05                   | 0.54                   |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 7.5° ATDC      |          | 9.5° BTDC |
| Idle rpm                     | 520 rpm        |          | 725 rpm   |
| PCV                          | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (180°) |          | Normal    |
| Idle CO                      | 0.5%           | 1.5%     | 3%        |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AB = CD             |           | -5.04*    |           |
| AD = BC             |           |           | 0.24*     |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 606

YEAR: 1969      MAKE: Ford      CID: 302      EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 202.1*          | 0.074         | 1084.8*         |
| B | Idle rpm    | -166.2*         | 0.122*        | -86.7           |
| C | PCV         | -32.2*          | -0.422*       | 720.8*          |
| D | Air Cleaner | -24.3           | -0.010        | -21.9           |
| E | Idle CO     | -44.4/-8.1*     | 0.215/0.211*  | -220.2/338.1    |
|   | Residuals   | 34              | 0.16          | 128             |

Parameter Adjustments

|             | <u>-1</u>                   | <u>0</u> | <u>+1</u>            |
|-------------|-----------------------------|----------|----------------------|
| Timing      | 4 <sup>0</sup> ATDC         |          | 13 <sup>0</sup> BTDC |
| Idle rpm    | 440                         |          | 605                  |
| PCV         | Plugged                     |          | Normal               |
| Air Cleaner | Plugged (165 <sup>0</sup> ) |          | Normal               |
| Idle CO     | 1.7%                        | 2.7%     | 4.2%                 |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            | -27.2*    |           | -156*     |
| BE1                | 55.5*     |           |           |
| BE2                | 17.8*     |           |           |

\*Statistically significant at 90 per cent confidence level.

MASS EMISSIONS  
Car 606

YEAR: 1969

MAKE: Ford

CID: 302

EMISS. DEV: E.M.

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 1.41*                   | -5.0*                  | 3.44*                  |
| B | Idle rpm    | -1.77*                  | 9.49*                  | 0.30                   |
| C | PCV         | -0.70                   | -7.31*                 | 0.90                   |
| D | Air Cleaner | -0.44                   | 1.56                   | -0.03                  |
| E | Idle CO     | -0.71/0.93              | 9.11/10.26*            | -0.16/0.02             |
|   | Residuals   | 1.09                    | 3.42                   | 1.46                   |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 4° ATDC        |          | 13° BTDC  |
| Idle rpm                     | 440 RPM        |          | 605 RPM   |
| PCV                          | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (165°) |          | Normal    |
| Idle CO                      | 1.7%           | 2.7%     | 4.2%      |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AD = BC             |           | -1.57*    |           |
| BE1                 |           | 2.56*     |           |
| BE2                 |           | 2.35*     |           |
| DE1                 |           | 5.51*     |           |
| DE2                 |           | 0.33*     |           |

\*Statistically significant at 90 per cent confidence level.



COMPOSITE EMISSIONS  
Car 607

YEAR: 1969

MAKE: V.W.

CID: 92

EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 83.7*           | -0.174*       | 668.2*          |
| B | Idle rpm    | -246.2*         | 0.136         | 84.4            |
| C | PCV         | 29.8            | 0.120         | -99.8*          |
| D | Air Cleaner | -38.0           | -0.472*       | 128.7*          |
| E | Idle CO     | -26.9/-43.6     | 0.179/0.123*  | -141.8/96.5     |
|   | Residuals   | 95              | 0.22          | 129             |

Parameter Adjustments

|             | <u>-1</u>            | <u>0</u> | <u>+1</u>           |
|-------------|----------------------|----------|---------------------|
| Timing      | 10 <sup>0</sup> ATDC |          | 7 <sup>0</sup> BTDC |
| Idle rpm    | 680                  |          | 935                 |
| PCV         | Plugged              |          | Normal              |
| Air Cleaner | Plugged (1.9%)       |          | Normal (1.9%)       |
| Idle CO     | 4.0%                 | 5.0%     | 6.5%                |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| None*              |           |           |           |

\*Statistically significant at 90 per cent confidence level.

MASS EMISSIONS  
Car 607

YEAR: 1969 MAKE: V.W. CID: 91 EMISS. DEV: E.M.

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | -0.14                   | -5.25*                 | 0.94*                  |
| B | Idle rpm    | -0.97*                  | 7.04*                  | -0.07                  |
| C | PCV         | -0.03                   | 1.68                   | -0.10                  |
| D | Air Cleaner | 0.32*                   | -9.64*                 | 0.33*                  |
| E | Idle CO     | -0.046/0.185            | 4.60/3.83*             | -0.21/0.23             |
|   | Residuals   | 0.41                    | 4.15                   | 0.28                   |

| <u>Parameter Adjustments</u> |           |          |           |
|------------------------------|-----------|----------|-----------|
|                              | <u>-1</u> | <u>0</u> | <u>+1</u> |
| Timing                       | 10° ATDC  |          | 7° BTDC   |
| Idle rpm                     | 680 RPM   |          | 935 RPM   |
| PCV                          | Plugged   |          | Normal    |
| Air Cleaner                  | Plugged   |          | Normal    |
| Idle CO                      | 4%        | 5%       | 6.5%      |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AE1                 |           |           | 0.12      |
| AE2                 |           |           | -0.40     |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 608

YEAR: 1968      MAKE: Plymouth      CID: 318      EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 94.6*           | 0.129*        | 597.9*          |
| B | Idle rpm    | -25.0*          | 0.093         | -12.8           |
| C | PCV         | -33.7*          | -0.698*       | 347.1*          |
| D | Air Cleaner | -11.3           | -0.344*       | 38.7            |
| E | Idle CO     | 10.2/11.1       | 0.415/0.442*  | -1.9/-131.2*    |
|   | Residuals   | 19              | 0.17          | 106             |

Parameter Adjustments

|             | <u>-1</u>                   | <u>0</u> | <u>+1</u>             |
|-------------|-----------------------------|----------|-----------------------|
| Timing      | 12.5 <sup>0</sup> ATDC      |          | 4.5 <sup>0</sup> BTDC |
| Idle rpm    | 520                         |          | 715                   |
| PCV         | Plugged                     |          | Normal                |
| Air Cleaner | Plugged (165 <sup>0</sup> ) |          | Normal                |
| Idle CO     | 0.5%                        | 1.5%     | 3.0%                  |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u>                  | <u>NO</u> |
|--------------------|-----------|----------------------------|-----------|
| AC = BD            |           |                            | 62.1 *    |
| AD = BC            |           | 6.370 x 10 <sup>-2</sup> * |           |
| AE1                |           | 0.232*                     | -65.6*    |
| AE2                |           | -0.054*                    | -90.6*    |

\*Statistically significant at 90 per cent confidence level.

MASS EMISSIONS  
Car 608

YEAR: 1968 MAKE: Plym(Barcda) CID: 318 EMISS. DEV: E.M.

Emission Changes

|               | <u>HC (grams/mile)</u> | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
|---------------|------------------------|------------------------|------------------------|
| A Timing      | 0.46                   | -1.54                  | 2.17*                  |
| B Idle rpm    | -0.41                  | 6.01*                  | -0.11                  |
| C PCV         | -0.64*                 | -12.17*                | 1.20*                  |
| D Air Cleaner | -0.02                  | -8.61*                 | 0.66                   |
| E Idle CO     | 0.20/0.13              | 14.94/15.55*           | 0.10/-0.28             |
| Residuals     | 0.70                   | 3.67                   | 1.01                   |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u> |
|-------------|----------------|----------|-----------|
| Timing      | 12.5° ATDC     |          | 4.5° BTDC |
| Idle rpm    | 520 RPM        |          | 715 RPM   |
| PCV         | Plugged        |          | Normal    |
| Air Cleaner | Plugged (165°) |          | Normal    |
| Idle CO     | 0.5%           | 1.5%     | 3%        |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AC = BD            |           | -1.85*    | 0.54*     |
| AD = BC            |           | 2.07*     |           |
| BE1                |           | 5.12*     |           |
| BE2                |           | 0.77*     |           |
| DE1                |           | 2.24*     |           |
| DE2                |           | -5.12*    |           |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 609

YEAR: 1970

MAKE: Chevrolet

CID: 350

EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 174.2*          | -0.344*       | 590.0*          |
| B | Idle rpm    | 106.1*          | 0.171*        | -25.4           |
| C | PCV         | -37.8           | -0.319*       | 107.9*          |
| D | Air Cleaner | 33.9            | 0.107*        | -78.7           |
| E | Idle CO     | 39.9/-50.5      | 0.088/0.296*  | 36.5/-17.0      |
|   | Residuals   | 77              | 0.076         | 130             |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u> |
|-------------|----------------|----------|-----------|
| Timing      | 6° ATDC        |          | 11° BTDC  |
| Idle rpm    | 480            |          | 660       |
| PCV         | Plugged        |          | Normal    |
| Air Cleaner | Plugged (180°) |          | Normal    |
| Idle CO     | 0.5%           | 1.5%     | 3.0%      |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u>                   | <u>NO</u> |
|--------------------|-----------|-----------------------------|-----------|
| AB = CD            | -45.9*    | -0.138*                     |           |
| AC = BD            |           | -3.886 x 10 <sup>-2</sup> * |           |
| BE1                |           | -0.125*                     |           |
| BE2                |           | 0.156*                      |           |
| CE1                |           | -0.123*                     |           |
| CE2                |           | 0.025*                      |           |
| DE1                |           | 0.133*                      |           |
| DE2                |           | -0.086*                     |           |

\*Statistically significant at 90 per cent confidence level.

MASS EMISSIONS  
Car 609

YEAR: 1970 MAKE: Chevrolet CID: 350 EMISS. DEV: E.M.

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 1.22*                   | -23.64*                | 2.66*                  |
| B | Idle rpm    | -0.76*                  | 0.16                   | 0.32                   |
| C | PCV         | -0.12                   | -7.60                  | 0.92                   |
| D | Air Cleaner | 0.23                    | 1.24                   | 0.50                   |
| E | Idle CO     | 0.31/-0.30              | 17.06/0.28             | 0.09/-0.98             |
|   | Residuals   | 0.63                    | 17.78                  | 1.32                   |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 6° ATDC        |          | 11° BTDC  |
| Idle rpm                     | 480 RPM        |          | 660 RPM   |
| PCV                          | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (180°) |          | Normal    |
| Idle CO                      | 0.5%           | 1.5%     | 3.0%      |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AB = CD             | -3.21     |           | 0.589     |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 610

YEAR: 1969      MAKE: Chevrolet      CID: 230      EMISS. DEV: Air

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 120.3*          | -0.211*       | 525.7*          |
| B | Idle rpm    | -146.0*         | 0.115         | 8.4             |
| C | Air Pump    | -216.9*         | -1.325*       | -70.4           |
| D | Air Cleaner | 53.0            | -0.231*       | 287.3*          |
| E | Idle CO     | 59.9/-75.2      | -0.153/0.503* | 188.8/-158.5    |
|   | Residuals   | 96              | .26           | 200             |

Parameter Adjustments

|             | <u>-1</u>                   | <u>0</u> | <u>+1</u>           |
|-------------|-----------------------------|----------|---------------------|
| Timing      | 10 <sup>0</sup> ATDC        |          | 7 <sup>0</sup> BTDC |
| Idle rpm    | 560                         |          | 770                 |
| Air Pump    | Plugged                     |          | Normal              |
| Air Cleaner | Plugged (175 <sup>0</sup> ) |          | Normal              |
| Idle CO     | 5.5%                        | 6.5%     | 8.0%                |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            |           | -0.191*   |           |
| AC = BD            |           | 0.281*    |           |
| AD = BC            |           | -0.317*   | 116*      |
| CE1                |           | -0.194*   |           |
| CE2                |           | -0.240*   |           |

\*Statistically significant at 90 per cent confidence level.



MASS EMISSIONS  
Car 610

YEAR: 1969 MAKE: Chevrolet CID: 230 EMISS. DEV: Air

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 0.66*                   | -14.30*                | 1.64*                  |
| B | Idle rpm    | -1.22*                  | 8.50*                  | 0.18                   |
| C | Air Pump    | -3.25*                  | -39.39*                | 0.02                   |
| D | Air Cleaner | -0.16                   | -7.90*                 | 0.36                   |
| E | Idle CO     | -0.07/.25               | -9.78/18.21*           | 0.46/-.53              |
|   | Residuals   | 0.75                    | 8.51                   | 0.5                    |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 10° ATDC       |          | 7° BTDC   |
| Idle rpm                     | 560 RPM        |          | 770 RPM   |
| Air Pump                     | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (175°) |          | Normal    |
| Idle CO                      | 5.5%           | 6.5%     | 8.0%      |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AC = BD             |           | 8.4*      |           |
| AD = BC             |           | -8.4*     |           |
| AE1                 |           | 1.42*     |           |
| AE2                 |           | -12.22*   |           |
| BE1                 | -0.08*    |           |           |
| BE2                 | 0.89*     |           |           |
| CE1                 | -1.07*    | -11.9*    |           |
| CE2                 | -0.12*    | -1.9*     |           |

\*Statistically significant at 90 per cent confidence level.

COMPOSITE EMISSIONS  
Car 611

YEAR: 1969      MAKE: Chevrolet      CID:250      EMISS. DEV: E.M.

Emission Changes

|   |             | <u>HC (ppm)</u> | <u>CO (%)</u> | <u>NO (ppm)</u> |
|---|-------------|-----------------|---------------|-----------------|
| A | Timing      | 138.6*          | 0.007         | 461.2*          |
| B | Idle rpm    | -109.7*         | 0.578*        | -158.9          |
| C | PCV         | -62.1*          | -0.445        | 159.8           |
| D | Air Cleaner | -73.1*          | -2.886*       | 187.5*          |
| E | Idle CO     | 5.2/3.1         | 0.321/0.372   | -239.2/74.2     |
|   | Residuals   | 60              | 0.68          | 255             |

Parameter Adjustments

|             | <u>-1</u>      | <u>0</u> | <u>+1</u> |
|-------------|----------------|----------|-----------|
| Timing      | 6° ATDC        |          | 11° BTDC  |
| Idle rpm    | 440            |          | 605       |
| PCV         | Plugged        |          | Normal    |
| Air Cleaner | Plugged (180°) |          | Normal    |
| Idle CO     | 2.5%           | 3.5%     | 5.0%      |

Interactions

| <u>Interaction</u> | <u>HC</u> | <u>CO</u> | <u>NO</u> |
|--------------------|-----------|-----------|-----------|
| AB = CD            |           |           | -107*     |
| AC = BD            |           |           | 104*      |
| AD = BC            |           |           | 128*      |

\*Statistically significant at 90 per cent confidence level.

MASS EMISSIONS  
Car 611

YEAR: 1969 MAKE: Chev. (Chville) CID: 250 EMISS. DEV: E.M.

|   |             | <u>Emission Changes</u> |                        |                        |
|---|-------------|-------------------------|------------------------|------------------------|
|   |             | <u>HC (grams/mile)</u>  | <u>CO (grams/mile)</u> | <u>NO (grams/mile)</u> |
| A | Timing      | 0.47*                   | 0.03                   | 3.85*                  |
| B | Idle rpm    | -0.46*                  | 10.98*                 | -0.27                  |
| C | PCV         | -0.16                   | -4.19                  | 0.09                   |
| D | Air Cleaner | -0.55*                  | -36.47*                | 0.29                   |
| E | Idle CO     | 0.04/-0.03              | 5.56/4.58*             | -1.40/0.61             |
|   | Residuals   | 0.24                    | 8.25                   | 1.65                   |

| <u>Parameter Adjustments</u> |                |          |           |
|------------------------------|----------------|----------|-----------|
|                              | <u>-1</u>      | <u>0</u> | <u>+1</u> |
| Timing                       | 6° ATDC        |          | 11° BTDC  |
| Idle rpm                     | 440 RPM        |          | 605 RPM   |
| PCV                          | Plugged        |          | Normal    |
| Air Cleaner                  | Plugged (180°) |          | Normal    |
| Idle CO                      | 2.5%           | 3.5%     | 5%        |

| <u>Interactions</u> |           |           |           |
|---------------------|-----------|-----------|-----------|
| <u>Interaction</u>  | <u>HC</u> | <u>CO</u> | <u>NO</u> |
| AD = BC             |           |           | 0.647*    |

\*Statistically significant at 90 per cent confidence level.

# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 601             |               |                                                                   |                  |
|------------|-------------------------|---------------|-------------------------------------------------------------------|------------------|
|            | 90 Percent Significance |               |                                                                   |                  |
|            | A<br>Timing             | B<br>Idle RPM | C<br>Change in Emission, $\Delta E$ , Low to High Parameter Level | E<br>Idle CO     |
|            |                         |               | D<br>Air Pump                                                     | D<br>Air Cleaner |
| Idle F     |                         |               | -4.310                                                            | +2.145           |
| Idle C     | -0.777                  |               | -4.984                                                            | +2.070           |
| 30-15 F    |                         |               | -5.543                                                            | +1.378           |
| 50-20 F    | -0.539                  | +0.443        | -5.509                                                            | +1.107           |
| 1500 RPM C |                         | -0.463        | -5.421                                                            | +1.934           |
| 30 F       | +0.246                  |               | -2.128                                                            | +7.408           |
| 33 C       |                         |               | -1.439                                                            | -0.318           |
| 0-25 F     | +0.351                  |               | -1.257                                                            | -0.609           |
| 15-30 F    |                         |               | -1.066                                                            | +0.390           |
| 50 C       | +0.373                  |               |                                                                   | -0.268           |
| WOT C      |                         |               | -1.780                                                            | -0.298           |
|            |                         |               |                                                                   | -0.361           |
|            |                         |               |                                                                   | +0.440           |

CO Diagnostic Mode Emission Sensitivity to Malfunction  
Vehicle 602

90 Percent Significance

| Mode       | Change in Emission, ΔE, Low to High Parameter Level |                      |                      |                         |
|------------|-----------------------------------------------------|----------------------|----------------------|-------------------------|
|            | A<br><u>Timing</u>                                  | B<br><u>Idle RPM</u> | C<br><u>Air Pump</u> | D<br><u>Air Cleaner</u> |
| Idle F     |                                                     |                      | -1.791               | Idle CO<br>+2.148       |
| Idle C     |                                                     | -0.409               | -2.340               | +2.021                  |
| 30-15 F    | -0.279                                              | -0.662               | -4.926               | +1.050                  |
| 50-20 F    |                                                     |                      | -3.744               | +1.019                  |
| 1500 RPM C | 0.505                                               | -0.507               | -2.683               | +1.779                  |
| 30 F       | +0.251                                              | -0.472               | -2.482               | -0.912                  |
| 33 C       |                                                     | -0.269               | -1.154               | -0.905                  |
| 0-25 F     |                                                     | -0.428               | -0.969               | -0.693                  |
| 15-30 F    |                                                     | -0.362               | -1.026               | -0.841                  |
| 50 C       |                                                     |                      | -0.638               | -1.322                  |
| WOT C      |                                                     | -0.585               | -2.296               | -1.023                  |
|            |                                                     |                      |                      | +0.254                  |
|            |                                                     |                      |                      | +0.146                  |
|            |                                                     |                      |                      | +0.421                  |

# CO Diagnostic Mode Emission Sensitivity to Malfunction

Vehicle 604

90 Percent Significance

Change in Emission,  $\Delta E$ , Low to High Parameter Level

| Mode       | A<br><u>Timing</u> | B<br>Idle RPM |  | C<br>Air Pump |  | D<br>Air Cleaner |  | E<br>Idle CO |  |
|------------|--------------------|---------------|--|---------------|--|------------------|--|--------------|--|
|            |                    |               |  |               |  |                  |  |              |  |
| Idle F     |                    | 0.195         |  |               |  |                  |  | +1.682       |  |
| Idle C     | +0.370             |               |  |               |  | +0.411           |  | +2.285       |  |
| 30-15 F    |                    | -0.969        |  |               |  |                  |  | +2.104       |  |
| 50-20 F    | -0.465             |               |  |               |  |                  |  | +1.192       |  |
| 1500 RPM C |                    |               |  |               |  |                  |  | +2.022       |  |
| 30 F       |                    |               |  | -1.316        |  | -1.284           |  |              |  |
| 33 C       |                    |               |  | -1.033        |  | -1.711           |  |              |  |
| 0-25 F     |                    |               |  | -1.172        |  | -1.322           |  |              |  |
| 15-30 F    |                    |               |  | -1.148        |  | -1.546           |  |              |  |
| 50 C       | -0.517             |               |  |               |  | -0.594           |  |              |  |
| WOT C      |                    |               |  | -1.177        |  | -1.201           |  |              |  |

## CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode          | Vehicle 605                                                  |            |                    |                |  |
|---------------|--------------------------------------------------------------|------------|--------------------|----------------|--|
|               | 90 Percent Significance                                      |            |                    |                |  |
|               | Change in Emission, $\Delta E$ , Low to High Parameter Level |            |                    |                |  |
| A             | B                                                            | C          | D                  | E              |  |
| <u>Timing</u> | <u>Idle RPM</u>                                              | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |  |
| -0.186        | +0.200                                                       |            |                    | +2.654         |  |
|               |                                                              | +0.366     |                    | +2.858         |  |
|               | +0.176                                                       |            | -0.135             | +2.312         |  |
|               | +0.204                                                       |            |                    | +2.200         |  |
|               |                                                              |            |                    | +2.763         |  |
|               | +0.323                                                       |            | -0.299             | +0.303         |  |
| -0.421        | +0.200                                                       |            |                    |                |  |
| -0.445        | +0.345                                                       |            | -0.359             |                |  |
| -0.428        | +0.306                                                       |            |                    |                |  |
|               |                                                              |            | -1.046             |                |  |
| -0.293        | +0.267                                                       |            | -0.386             |                |  |



# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 606                                                  |                      |                 |                         |                     |
|------------|--------------------------------------------------------------|----------------------|-----------------|-------------------------|---------------------|
|            | 90 Percent Significance                                      |                      |                 |                         |                     |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |                      |                 |                         |                     |
|            | A<br><u>Timing</u>                                           | B<br><u>Idle RPM</u> | C<br><u>PCV</u> | D<br><u>Air Cleaner</u> | E<br><u>Idle CO</u> |
| Idle F     |                                                              | 0.165                |                 |                         | +2.505              |
| Idle C     |                                                              |                      |                 |                         | +2.530              |
| 30-15 F    | -0.687                                                       | +0.644               | -0.400          |                         | +1.674              |
| 50-20 F    | -0.383                                                       | +0.449               | +0.181          | +0.223                  | +1.647              |
| 1500 RPM C |                                                              |                      |                 |                         | +2.237              |
| 30 F       |                                                              | +0.056               | -0.185          |                         | +0.109              |
| 33 C       |                                                              |                      | -0.356          | -0.136                  |                     |
| 0-25 F     |                                                              |                      | -0.460          | -0.199                  |                     |
| 15-30 F    | +0.140                                                       |                      | -0.446          |                         |                     |
| 50 C       |                                                              |                      | -0.263          |                         |                     |
| WOT C      |                                                              |                      | 0.208           |                         |                     |

# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 607             |                    |                                                              |                         |                     |
|-------------------------|--------------------|--------------------------------------------------------------|-------------------------|---------------------|
| 90 Percent Significance |                    |                                                              |                         |                     |
| Mode                    | A<br><u>Timing</u> | Change in Emission, $\Delta F$ , Low to High Parameter Level |                         |                     |
|                         |                    | B<br><u>Idle RPM</u>                                         | D<br><u>Air Cleaner</u> | E<br><u>Idle CO</u> |
| Idle F                  |                    |                                                              |                         | +2.148              |
| Idle C                  |                    |                                                              |                         | +2.310              |
| 30-15 F                 | -0.896             | +1.146                                                       |                         | +1.738              |
| 50-20 F                 | -0.633             | +1.10                                                        |                         | +1.49               |
| 1500 RPM C              |                    |                                                              |                         | +2.257              |
| 30 F                    | -0.210             |                                                              | +0.112                  | +0.208              |
| 33 C                    |                    |                                                              | -0.158                  | +0.231              |
| 0-25 F                  |                    |                                                              | -0.208                  |                     |
| 15-30 F                 |                    |                                                              | -0.883                  |                     |
| 50 C                    | -0.134             |                                                              | -0.493                  |                     |
| WOT C                   |                    |                                                              | -0.422                  | +0.217              |

## Vehicle 608 F

B-29

## CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode          | Vehicle 609                                                  |            |                    |                |        |
|---------------|--------------------------------------------------------------|------------|--------------------|----------------|--------|
|               | 90 Percent Significance                                      |            |                    |                |        |
|               | Change in Emission, $\Delta E$ , Low to High Parameter Level |            |                    |                |        |
| A             | B                                                            | C          | D                  | E              |        |
| <u>Timing</u> | <u>Idle RPM</u>                                              | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |        |
| Idle F        | 0.180                                                        |            |                    |                | +2.575 |
| Idle C        | -0.329                                                       |            |                    |                | +2.382 |
| 30-15 F       | -0.414                                                       |            |                    |                | +2.161 |
| 50-20 F       | -0.984                                                       | +0.284     | -0.226             |                | +2.188 |
| 1500 RPM C    | -0.621                                                       |            |                    |                | +2.239 |
| 30 F          | -0.546                                                       |            |                    |                | +0.528 |
| 33 C          | +0.581                                                       |            |                    |                |        |
| 0-25 F        | +0.168                                                       | -0.499     | +0.211             |                |        |
| 15-30 F       | -0.538                                                       | -0.304     |                    |                |        |
| 50 C          | -0.138                                                       | -0.577     | +0.243             |                |        |
| WOT C         | -1.616                                                       | -0.360     |                    |                |        |

# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 610                                                  |                 |            |                    |                |
|------------|--------------------------------------------------------------|-----------------|------------|--------------------|----------------|
|            | 90 Percent Significance                                      |                 |            |                    |                |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |                 |            |                    |                |
|            | A                                                            | B               | C          | D                  | E              |
|            | <u>Timing</u>                                                | <u>Idle RPM</u> | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |
| Idle F     | +0.735                                                       | -0.772          | -5.372     |                    |                |
| Idle C     |                                                              |                 | -5.42      |                    |                |
| 30-15 F    |                                                              |                 | -4.522     |                    | +0.790         |
| 50-20 F    |                                                              | +0.467          | -4.345     |                    |                |
| 1500 RPM C |                                                              |                 | -5.556     |                    |                |
| 30 F       | -0.872                                                       | +0.542          | -1.359     |                    |                |
| 33 C       |                                                              |                 | -1.238     | -1.405             |                |
| 0-25 F     |                                                              |                 | -1.164     |                    |                |
| 15-30 F    |                                                              |                 | 0.611      | -0.197             | +0.144         |
| 50 C       |                                                              |                 |            |                    |                |
| WOT C      | -0.984                                                       | +0.408          | -1.530     | -0.344             |                |

# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 611 |             |                                                                                         |          |                  |
|-------------|-------------|-----------------------------------------------------------------------------------------|----------|------------------|
| Mode        | A<br>Timing | 90 Percent Significance<br>Change in Emission, $\Delta E$ , Low to High Parameter Level |          |                  |
|             |             | B<br>Idle RPM                                                                           | C<br>PCV | D<br>Air Cleaner |
|             |             |                                                                                         |          | E<br>Idle CO     |
| Idle F      |             | 0.165                                                                                   |          | +2.526           |
| Idle C      | +0.163      |                                                                                         |          | +2.396           |
| 30-15 F     |             | +0.331                                                                                  |          | +2.004           |
| 50-20 F     |             | +0.594                                                                                  |          | +1.802           |
| 1500 RPM C  |             |                                                                                         |          | +2.905           |
| 30 F        |             |                                                                                         |          |                  |
| 33 C        |             |                                                                                         |          |                  |
| 0-25 F      |             |                                                                                         | +0.056   |                  |
| 15-30 F     |             |                                                                                         |          |                  |
| 50 C        | +0.023      |                                                                                         |          |                  |
| WOT C       |             | +0.769                                                                                  | -0.051   |                  |
|             |             |                                                                                         |          | -1.882           |

# CO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode     | Vehicle 601                                                  |          |             |         |  |
|----------|--------------------------------------------------------------|----------|-------------|---------|--|
|          | 90 Percent Significance                                      |          |             |         |  |
|          | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |             |         |  |
| A        | B                                                            | C        | D           | E       |  |
| Timing   | Idle RPM                                                     | Air Pump | Air Cleaner | Idle CO |  |
| Idle F   | +166                                                         | -214     | -           | +55     |  |
| Idle C   | +165                                                         | -244     | -           | +49     |  |
| 30-15 F  | +302                                                         | -518     | -           | -       |  |
| 50-20 F  | +491                                                         | -1499    | -           | +354    |  |
| 1500 RPM | +143                                                         | -        | -           | +64     |  |
| 30 F     | +104                                                         | -164     | -           | -       |  |
| 33 C     | +82                                                          | -158     | -           | -       |  |
| 0-25 F   | +144                                                         | -135     | -           | -       |  |
| 15-30 F  | +129                                                         | -114     | -           | -       |  |
| 50 C     | +92                                                          | -40      | -           | -       |  |
| WOT C    | +87                                                          | -157     | -           | -       |  |

C = Clayton  
F = Federal



# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 602             |                                                              |               |               |                  |              |
|-------------------------|--------------------------------------------------------------|---------------|---------------|------------------|--------------|
| 90 Percent Significance |                                                              |               |               |                  |              |
| Mode                    | Change in Emission, $\Delta E$ , Low to High Parameter Level |               |               |                  |              |
|                         | A<br>Timing                                                  | B<br>Idle RPM | C<br>Air Pump | D<br>Air Cleaner | E<br>Idle CO |
| Idle F                  | +125                                                         | -49           | -157          | -                | -            |
| Idle C                  | +92                                                          | -32           | -149          | +16              | +47          |
| 30-15 F                 | +127                                                         | -51           | -320          | -                | +24          |
| 50-20 F                 | +510                                                         | -747          | -600          | -                | +203         |
| 1500 RPM C              | +109                                                         | -90           | -177          | +73              | -            |
| 30 F                    | +129                                                         | -36           | -249          | -26              | -            |
| 33 C                    | +82                                                          | -             | -145          | -                | -            |
| 0-25 F                  | +151                                                         | -47           | -140          | -15              | +17          |
| 15-30 F                 | +126                                                         | -27           | -160          | -21              | -            |
| 50 C                    | +65                                                          | -13           | -83           | -14              | +19          |
| WOT C                   | +123                                                         | -30           | -216          | -                | +24          |

C = Clayton  
F = Federal

## HC Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 604                                                                             |             |               |     |             |         |
|-----------------------------------------------------------------------------------------|-------------|---------------|-----|-------------|---------|
| 90 Percent Significance<br>Change in Emission, $\Delta E$ , Low to High Parameter Level |             |               |     |             |         |
| Mode                                                                                    | A<br>Timing | B<br>Idle RPM | D   |             |         |
|                                                                                         |             |               | PCV | Air Cleaner | Idle CO |
| Idle F                                                                                  | -           | -143          | -   | -143        | -       |
| Idle C                                                                                  | -           | -             | -   | -106        | -       |
| 30-15 F                                                                                 | +223        | -157          | -   | -           | -       |
| 50-20 F                                                                                 | +706        | -958          | -   | -192        | -103    |
| 1500 RPM C                                                                              | -           | -             | -   | -394        | -520    |
| 30 F                                                                                    | +110        | -             | -30 | -34         | -       |
| 33 C                                                                                    | +151        | -             | -   | -59         | -       |
| 0-25 F                                                                                  | +143        | -42           | -   | -69         | -40     |
| 15-30 F                                                                                 | +139        | -             | -22 | -50         | -       |
| 50 C                                                                                    | +80         | -             | -   | -39         | -       |
| WOT C                                                                                   | +129        | -             | -45 | -45         | -       |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 605                                                  |               |          |                  |              |
|------------|--------------------------------------------------------------|---------------|----------|------------------|--------------|
|            | 90 Percent Significance                                      |               |          |                  |              |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |               |          |                  |              |
|            | A<br>Timing                                                  | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F     | -                                                            | -             | -        | -                | -            |
| Idle C     | -                                                            | -             | -        | -                | -            |
| 0-15 F     | -                                                            | -562          | -        | -                | -671         |
| 0-20 F     | -                                                            | -867          | -        | -                | -1187        |
| 1500 RPM C | -                                                            | -600          | -        | -                | -            |
| 30 F       | +22                                                          | -19           | -        | -                | -            |
| 33 C       | +21                                                          | -14           | -        | -                | -            |
| 0-25 F     | -                                                            | -             | -        | -                | -            |
| 15-30 F    | +30                                                          | -             | -        | -                | -            |
| 50 C       | +20                                                          | -10           | -        | -33              | -            |
| WOT C      | +25                                                          | -24           | -        | -                | -            |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 606                                                  |             |               |          |                  |              |
|--------------------------------------------------------------|-------------|---------------|----------|------------------|--------------|
| 90 Percent Significance                                      |             |               |          |                  |              |
| Change in Emission, $\Delta E$ , Low to High Parameter Level |             |               |          |                  |              |
| Mode                                                         | A<br>Timing | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F                                                       | +341        | -258          | -        | -                | -            |
| Idle C                                                       | -           | -             | -        | -                | -            |
| 30-15 F                                                      | +373        | -444          | -127     | -                | -211         |
| 50-20 F                                                      | +807        | -1575         | -        | -                | -            |
| 1500 RPM C                                                   | +419        | -289          | -        | -                | -            |
| 30 F                                                         | +123        | -64           | -26      | -24              | -            |
| 33 C                                                         | -           | -             | -        | -                | -            |
| 0-25 F                                                       | +202        | -141          | -        | -39              | -            |
| 15-30 F                                                      | +118        | -54           | -32      | -16              | -            |
| 50 C                                                         | -           | -             | -        | -                | -            |
| WOT C                                                        | -           | -             | -        | -                | -            |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 607                                                  |               |          |                  |              |
|------------|--------------------------------------------------------------|---------------|----------|------------------|--------------|
|            | 90 Percent Significance                                      |               |          |                  |              |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |               |          |                  |              |
|            | A<br>Timing                                                  | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F     | +120                                                         | -146          | +34      | -                | -            |
| Idle C     | +103                                                         | -89           | -        | -                | -            |
| 30-15 F    | -                                                            | -1892         | -        | -                | -736         |
| 50-20 F    | -                                                            | -1933         | -        | -                | -            |
| 1500 RPM C | +95                                                          | -120          | -        | -62              | -            |
| 30 F       | +63                                                          | -34           | -        | -                | -            |
| 33 C       | +90                                                          | -47           | -        | -                | -            |
| 0-25 F     | +149                                                         | -             | -        | -                | -            |
| 15-30 F    | +79                                                          | -             | -        | -                | -            |
| 50 C       | +58                                                          | -35           | -        | -                | -            |
| WOT C      | -                                                            | -             | -        | -                | -            |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 608                                                  |                      |                 |                         |                     |
|------------|--------------------------------------------------------------|----------------------|-----------------|-------------------------|---------------------|
|            | 90 Percent Significance                                      |                      |                 |                         |                     |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |                      |                 |                         |                     |
|            | A<br><u>Timing</u>                                           | B<br><u>Idle RPM</u> | C<br><u>PCV</u> | D<br><u>Air Cleaner</u> | E<br><u>Idle CO</u> |
| Idle F     | +81                                                          | -                    | -               | -                       | +72                 |
| Idle C     | +70                                                          | -                    | -25             | -                       | +88                 |
| 30-15 F    | +78                                                          | -43                  | -               | -                       | +42                 |
| 50-20 F    | +158                                                         | -479                 | -               | +239                    | -332                |
| 1500 RPM C | +62                                                          | -16                  | -17             | -                       | +67                 |
| 30 F       | +92                                                          | -11                  | -30             | -17                     | +31                 |
| 33 C       | +63                                                          | -                    | -34             | -19                     | -                   |
| 0-25 F     | +92                                                          | +5                   | -28             | -17                     | +33                 |
| 15-30 F    | +86                                                          | -                    | -34             | -25                     | +24                 |
| 50 C       | +40                                                          | -                    | -19             | -19                     | -                   |
| WOT C      | +84                                                          | -                    | -27             | -                       | +23                 |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

Vehicle 609

90 Percent Significance

| Mode       | Change in Emission, $\Delta E$ , Low to High Parameter Level |               |          |                  |              |
|------------|--------------------------------------------------------------|---------------|----------|------------------|--------------|
|            | A<br>Timing                                                  | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F     | +278                                                         | -             | -        | -                | -            |
| Idle C     | +217                                                         | -             | -        | -                | -            |
| 30-15 F    | +581                                                         | -564          | -        | -                | -            |
| 50-20 F    | +959                                                         | -1034         | -        | -                | -            |
| 1500 RPM C | -                                                            | -             | -        | -                | -            |
| 30 F       | +54                                                          | +33           | -7       | -                | +29          |
| 33 C       | +46                                                          | -             | -37      | -                | -            |
| 0-25 F     | +85                                                          | -37           | -        | -                | -            |
| 15-30 F    | +87                                                          | -13           | -29      | +22              | -            |
| 50 C       | +63                                                          | -             | -        | -                | -            |
| WOT C      | +32                                                          | -             | -        | -                | -            |

C = Clayton  
F = Federal



# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 610                                                  |          |             |         |   |
|------------|--------------------------------------------------------------|----------|-------------|---------|---|
|            | 90 Percent Significance                                      |          |             |         |   |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |             |         |   |
| A          | B                                                            | C        | D           | E       |   |
| Timing     | Idle RPM                                                     | Air Pump | Air Cleaner | Idle CO |   |
| Idle F     | +167                                                         | -243     | -           | -       | - |
| Idle C     | +127                                                         | -182     | -           | -       | - |
| 30-15 F    | -                                                            | -764     | -           | -       | - |
| 50-20 F    | +883                                                         | -1490    | -           | -       | - |
| 1500 RPM C | +134                                                         | -218     | -           | -       | - |
| 30 F       | +61                                                          | -166     | -           | -       | - |
| 33 C       | +94                                                          | -112     | -           | -       | - |
| 0-25 F     | -                                                            | -229     | +142        | -       | - |
| 15-30 F    | +93                                                          | -131     | -           | -       | - |
| 50 C       | +54                                                          | -96      | -           | -       | - |
| WOT C      | -                                                            | -115     | -           | -       | - |

C = Clayton  
F = Federal

# HC Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 611                                                  |     |             |         |  |
|------------|--------------------------------------------------------------|-----|-------------|---------|--|
|            | 90 Percent Significance                                      |     |             |         |  |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |     |             |         |  |
| A          | B                                                            | C   | D           | E       |  |
| Timing     | Idle RPM                                                     | PCV | Air Cleaner | Idle CO |  |
| Idle F     | +102                                                         | -   | -           | +55     |  |
| Idle C     | +83                                                          | -   | -           | +42     |  |
| 30-15 F    | +186                                                         | -   | -110        | -       |  |
| 50-20 F    | +448                                                         | -   | -           | -       |  |
| 1500 RPM C | -                                                            | -   | -           | -       |  |
| 30 F       | +82                                                          | -   | -84         | +53     |  |
| 33 C       | +53                                                          | -   | -24         | -       |  |
| 0-25       | +72                                                          | -   | -82         | -       |  |
| 15-30 F    | +116                                                         | -84 | -61         | -       |  |
| 50 C       | +26                                                          | -   | -23         | -       |  |
| WOT C      | +119                                                         | -   | -46         | -       |  |

C = Clayton  
F = Federal

# NO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 601                                                  |          |             |         |   |
|------------|--------------------------------------------------------------|----------|-------------|---------|---|
|            | 90 Percent Significance                                      |          |             |         |   |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |             |         |   |
| A          | B                                                            | C        | D           | E       |   |
| Timing     | Idle RPM                                                     | Air Pump | Air Cleaner | Idle CO |   |
| Idle F     | +22                                                          | -        | -           | -       | - |
| Idle C     | +19                                                          | -19      | -           | -       | - |
| 30-15 F    | +57                                                          | -36      | -           | -       | - |
| 50-20 F    | +182                                                         | -64      | -           | -       | - |
| 1500 RPM C | -                                                            | -29      | -           | -       | - |
| 30 F       | +327                                                         | -107     | +82         | -148    | - |
| 33 C       | +627                                                         | -247     | +270        | -       | - |
| 0-25 F     | +509                                                         | -87      | -           | -       | - |
| 15-30 F    | +569                                                         | -181     | -           | -       | - |
| 50 C       | +1275                                                        | -204     | -           | -       | - |
| WOT C      | +550                                                         | -181     | +117        | -       | - |

C = Clayton  
F = Federal

# NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 602                                         |          |             |         |  |
|------------|-----------------------------------------------------|----------|-------------|---------|--|
|            | 90 Percent Significance                             |          |             |         |  |
|            | Change in Emission, ΔF, Low to High Parameter Level |          |             |         |  |
| A          | B                                                   | C        | D           | E       |  |
| Timing     | Idle RPM                                            | Air Pump | Air Cleaner | Idle CO |  |
| Idle F     | +17                                                 | -15      | -           | -24     |  |
| Idle C     | -                                                   | -        | -           | -       |  |
| 30-15 F    | +60                                                 | -        | +31         | -25     |  |
| 50-20 F    | +60                                                 | -        | +60         | -       |  |
| 1500 RPM C | -                                                   | -        | -           | -       |  |
| 30 F       | +322                                                | -        | +140        | -       |  |
| 33 C       | +617                                                | -207     | +410        | -       |  |
| 0-25 F     | +492                                                | -84      | -140        | -       |  |
| 15-30 F    | +531                                                | -69      | +247        | -       |  |
| 50 C       | +499                                                | -223     | +636        | -       |  |
| WOT C      | +375                                                | -        | +197        | -       |  |

C = Clayton  
F = Federal

# NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 604                                                  |      |             |         |   |
|------------|--------------------------------------------------------------|------|-------------|---------|---|
|            | 90 Percent Significance                                      |      |             |         |   |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |      |             |         |   |
| A          | B                                                            | C    | D           | E       |   |
| Timing     | Idle RPM                                                     | PCV  | Air Cleaner | Idle CO |   |
| Idle F     | -                                                            | -    | +28         | -       | - |
| Idle C     | -                                                            | -40  | -           | -       | - |
| 30-15 F    | -                                                            | -    | +24         | -       | - |
| 50-20 F    | +153                                                         | -    | -           | -       | - |
| 1500 RPM C | -                                                            | -30  | -           | -       | - |
| 30 F       | +84                                                          | -    | +99         | -       | - |
| 33 C       | +533                                                         | +157 | +248        | -       | - |
| 0-25 F     | +392                                                         | +188 | +223        | -       | - |
| 15-30 F    | +457                                                         | +175 | +251        | -       | - |
| 50 C       | +1321                                                        | -    | -           | -       | - |
| WOT C      | +148                                                         | -    | +102        | -       | - |

C = Clayton  
F = Federal

# NO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 605                                                  |               |          |                  |              |
|------------|--------------------------------------------------------------|---------------|----------|------------------|--------------|
|            | 90 Percent Significance                                      |               |          |                  |              |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |               |          |                  |              |
|            | A<br>Timing                                                  | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F     | -                                                            | +24           | -        | -                | -20          |
| Idle C     | -                                                            | -             | -        | -                | -            |
| 30-15F     | +34                                                          | -             | -        | -                | -            |
| 50-20 F    | +74                                                          | -             | -        | -                | -            |
| 1500 RPM C | -10                                                          | +19           | -        | -                | -            |
| 30 F       | +253                                                         | -168          | -        | +145             | -            |
| 33 C       | +978                                                         | -239          | -        | -                | -            |
| 0-25 F     | -                                                            | -             | -62      | -                | +123         |
| 15-30 F    | +692                                                         | -105          | -        | -126             | -            |
| 50 C       | +1061                                                        | -             | -        | +353             | -            |
| WOT C      | +493                                                         | -196          | -150     | +141             | -            |

C = Clayton  
F = Federal

# NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

| Mode          | Vehicle 606                                                  |            |                    |                |  |
|---------------|--------------------------------------------------------------|------------|--------------------|----------------|--|
|               | 90 Percent Significance                                      |            |                    |                |  |
|               | Change in Emission, $\Delta E$ , Low to High Parameter Level |            |                    |                |  |
| A             | B                                                            | C          | D                  | E              |  |
| <u>Timing</u> | <u>Idle RPM</u>                                              | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |  |
| Idle F        | +30                                                          | +31        | -                  | -              |  |
| Idle C        | -                                                            | -          | +38                | -40            |  |
| 30-15 F       | +368                                                         | -          | -                  | -              |  |
| 50-20 F       | +97                                                          | -          | -                  | -              |  |
| 1500 RPM C    | -                                                            | -          | +35                | -              |  |
| 30 F          | +1694                                                        | -          | -                  | -              |  |
| 33 C          | +982                                                         | -          | -                  | -              |  |
| 0-25 F        | +834                                                         | +487       | -                  | -              |  |
| 15-30 F       | +1187                                                        | +1063      | -                  | -              |  |
| 50 C          | +872                                                         | -          | -                  | -              |  |
| WOT C         | +1419                                                        | -          | -                  | -              |  |

C = Clayton  
F = Federal



# NO<sub>x</sub> Diagnostic Mode Emission Sensitivity to Malfunction

Vehicle 607

90 Percent Significance

| Mode       | A<br>Timing | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |                  |
|------------|-------------|--------------------------------------------------------------|----------|------------------|
|            |             | B<br>Idle RPM                                                | C<br>PCV | D<br>Air Cleaner |
| Idle F     | -15         | +14                                                          | -        | -                |
| Idle C     | -           | -                                                            | -        | -                |
| 0-15 F     | +92         | -                                                            | -        | -                |
| 50-20 F    | -           | -                                                            | -        | +83              |
| 1500 RPM C | -28         | -                                                            | +8       | +8               |
| 30 F       | +700        | -                                                            | -126     | -                |
| 33 C       | +664        | -                                                            | -        | -                |
| 0-25 F     | +525        | -                                                            | -        | +260             |
| 15-30 F    | +874        | -                                                            | -117     | +137             |
| 50 C       | +977        | +113                                                         | -        | -                |
| WOT C      | +636        | -                                                            | -116     | -                |
|            |             |                                                              |          | -42              |

C = Clayton  
F = Federal

# NO Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 608                                         |               |                 |            |                    |                |
|-----------------------------------------------------|---------------|-----------------|------------|--------------------|----------------|
| 90 Percent Significance                             |               |                 |            |                    |                |
| Change in Emission, ΔE, Low to High Parameter Level |               |                 |            |                    |                |
| Mode                                                | A             | B               | C          | D                  | E              |
|                                                     | <u>Timing</u> | <u>Idle RPM</u> | <u>PCV</u> | <u>Air Cleaner</u> | <u>Idle CO</u> |
| Idle F                                              | -             | -               | -          | -66                | -64            |
| Idle C                                              | -             | +49             | -          | -                  | -              |
| 30-15 F                                             | +62           | -               | +36        | -                  | -              |
| 50-20 F                                             | +134          | -               | +59        | -                  | -              |
| 1500 RPM C                                          | -             | -               | -          | -27                | -              |
| 30 F                                                | +490          | -               | +168       | -                  | -171           |
| 33 C                                                | +923          | -               | +365       | +187               | -288           |
| 0-25 F                                              | +504          | -               | +329       | -                  | -119           |
| 15-30 F                                             | +813          | -               | +469       | -                  | -              |
| 50 C                                                | +1072         | -               | +331       | +138               | -              |
| WOT C                                               | +558          | -92             | +185       | -                  | -210           |

C = Clayton  
F = Federal

## NO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode        | Vehicle 609                                                  |          |                  |              |  |
|-------------|--------------------------------------------------------------|----------|------------------|--------------|--|
|             | 90 Percent Significance                                      |          |                  |              |  |
|             | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |                  |              |  |
| A<br>Timing | B<br>Idle RPM                                                | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |  |
| Idle F      | +91                                                          | -        | -                | -54          |  |
| Idle C      | +125                                                         | -        | -                | -59          |  |
| 30-15 F     | +223                                                         | -        | -                | -            |  |
| 50-20 F     | +102                                                         | -        | -                | -            |  |
| 1500 RPM    | +33                                                          | -        | -                | -30          |  |
| 30 F        | -                                                            | -        | -                | -            |  |
| 33 C        | -                                                            | -        | -                | -            |  |
| 0-25 F      | -                                                            | -        | -                | -            |  |
| 15-30 F     | +863                                                         | +130     | -84              | +1           |  |
| 50 C        | +1474                                                        | -        | -                | -            |  |
| WOT C       | +474                                                         | -        | -                | -            |  |

C = Clayton  
F = Federal

# NO Diagnostic Mode Emission Sensitivity to Malfunction

| Mode       | Vehicle 610                                                  |          |             |         |   |
|------------|--------------------------------------------------------------|----------|-------------|---------|---|
|            | 90 Percent Significance                                      |          |             |         |   |
|            | Change in Emission, $\Delta E$ , Low to High Parameter Level |          |             |         |   |
| A          | B                                                            | C        | D           | E       |   |
| Timing     | Idle RPM                                                     | Air Pump | Air Cleaner | Idle CO |   |
| Idle F     | -                                                            | -        | -           | -       | - |
| Idle C     | -                                                            | -        | -           | -       | - |
| 30-15 F    | +42                                                          | -57      | +45         | -23     | - |
| 50-20 F    | +158                                                         | -101     | -           | -       | - |
| 1500 RPM C | -12                                                          | -        | -           | -19     | - |
| 30 F       | +239                                                         | -187     | +173        | -34     | - |
| 33 C       | +964                                                         | -        | +515        | -       | - |
| 0-25 F     | +444                                                         | -174     | +268        | -       | - |
| 15-30 F    | +674                                                         | -336     | +244        | -       | - |
| 50 C       | +2046                                                        | -481     | -           | -       | - |
| WOT C      | +382                                                         | -        | +229        | -       | - |

C = Clayton  
F = Federal

# NO Diagnostic Mode Emission Sensitivity to Malfunction

| Vehicle 611                                                  |             |               |          |                  |              |
|--------------------------------------------------------------|-------------|---------------|----------|------------------|--------------|
| 90 Percent Significance                                      |             |               |          |                  |              |
| Change in Emission, $\Delta E$ , Low to High Parameter Level |             |               |          |                  |              |
| Mode                                                         | A<br>Timing | B<br>Idle RPM | C<br>PCV | D<br>Air Cleaner | E<br>Idle CO |
| Idle F                                                       | -14         | +20           | -        | +16              | -32          |
| Idle C                                                       | -           | +16           | -        | -13              | -            |
| 30-15 F                                                      | +120        | -             | -        | -117             | -            |
| 50-20 F                                                      | -142        | -             | -        | -                | -            |
| 1500 RPM C                                                   | -17         | +25           | -        | -                | -            |
| 30 F                                                         | +534        | -             | -        | +653             | -            |
| 33 C                                                         | +1108       | -             | -        | -                | -            |
| 0-25 F                                                       | -           | -             | -        | -                | -            |
| 15-30 F                                                      | +689        | -             | -        | -                | -            |
| 50 C                                                         | -1069       | -             | -        | -468             | -            |
| WOT C                                                        | +521        | -             | -        | -                | -            |

C = Clayton  
F = Federal